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CORRECTIONS

MONTHLY WEATHER REVIEW, October, 1928:

Page 399, first column, fifth paragraph, third line, "logs" should be "lags"; next column, sixth line above Figure 1, "best" should be "beat."

Pages 399–400, the legends to Figures 1 and 2 should be interchanged.

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A CRITIQUE ON THE CONSTRUCTION AND USE OF MINIMUM-TEMPERATURE FORMULAS

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[Weather Bureau, Pomona, Calif., October 21, 1928]

INTRODUCTION

Considerable attention during the last decade has been directed toward the development of methods for forecasting the minimum temperature using empirical mathematical formulas. Many formulas have been suggested, some of which are inherently faulty. This paper attempts to consider the subject as an entity to ascertain the relative merits of the different systems proposed, and to delineate the limitations that necessarily must exist in the construction and application of minimum temperature formulas in actual forecasting practice.

GENERAL CONSIDERATIONS

Frost usually occurs under conditions of high barometric pressure or when the weather is passing to anticyclonic control following the progression of a cyclone. Atmospheric stability is pronounced. Weather changes are due chiefly to insolation and rising temperature in the daytime coupled with free radiation and falling temperature at night. From the regularity of the nocturnal fall in temperature under ideal frost conditions, i. e., clear skies, no wind to disturb the stratification of the lower layers of the atmosphere, and the temperature falling under the influence of free radiation to a point below freezing at sunrise, it is but a step to the enumeration and mathematical expression of the various factors that operate collectively to produce these changes.

Under ideal frost conditions the more important factors that influence the minimum temperature at any given point can be enumerated:

1. *Temperature of the radiating surface.*—The rate of radiation varies as the 4th power of the absolute temperature of the radiating surface. Let this factor be expressed symbolically as T.

2. *Length of night, or interval during which free radiation takes place.*—Symbolically, t.

3. *Absolute humidity.*—The atmosphere would be practically diathermanous were it not for the presence in it of water vapor, which possesses the property of absorbing to some extent the outgoing waves of heat radiation. The rate of radiation is inversely proportional to the absolute humidity. Symbolically expressed as A.

4. *Liberation of latent heat from condensation and fusion of atmospheric moisture under special conditions.*—Symbolically expessed as L.

5. *Topographical situation of station.*—Points on the valley floor, in general, are colder than points on the surrounding hillsides due to the effects of air drainage. (1) The minimum temperature at any point, then, would depend upon the degree of temperature inversion prevailing and the relative location of this point in the stratified lower atmosphere. Symbolically expressed as a function of the temperature inversion, $f(I)$.

If we denote the minimum temperature by y, the general equation for its evaluation under ideal frost conditions becomes:

$$y=f(T)+f(t)+f(A)+f(L)+f(I) \qquad (1)$$

It is reasonable to assume that the factor $f(t)$ can be neglected provided the data are developed by frost seasons, since the average length of the night would remain practically constant over the period of extreme frost danger in the short spring and autumn frost periods, while the longer winter frost period is centered over the winter solstice when the nights become progressively longer to the solstice and then become progressively shorter at the same rate.

INDEX TO TEMPERATURE OF RADIATING SURFACE

Humphreys states (2): "* * * the temperature of the surface layer of the atmosphere is chiefly controlled by the temperature of the greedily absorbing and freely radiating surface of the earth." If a thermometer is exposed 4½ feet above the ground in a fruit region (4) or other standard thermometer shelter, it has been found by experiment that even where the surface texture of the ground is made to vary between the extremes of bare black soil and luxuriant vegetation, there is very littler difference in temperature that can be attributed to the condition of the ground or radiating surface. (5) (6) (7). For the purpose of this paper it can be inferred that the free air temperature at a point 4½ feet above the ground is a direct function of the temperature of the freely absorbing and radiating ground surface, and as such can be used in lieu of the temperature of the radiating surface.

Now when it is considered that the rate of radiation at any given instant during the night chiefly depends upon the pair of values to be associated with the temperature of the radiating surface and the absolute humidity, and that for every pair of values so associated there is a

corresponding pair of values for the temperature of the dew point and the relative humidity, it is possible to express equation 1, empirically, as

$$y=f(d)+f(h)+f(I) \tag{2}$$

where d and h are the temperature of the dew point and the relative humidity, respectively.

The factor $f(L)$ is considered to be taken care of by the new factor $f(h)$, since the higher the numerical value of the relative humidity at sunset, the greater is the probability of the dew point temperature being reached, and conversely. Some error necessarily is introduced here since the factor $f(L)$ is only indirectly represented by the factor $f(h)$, but when it is considered that the air temperature often remains quite stationary for several hours after the temperature of the dew point has been reached, it is seen that this error usually is of small order. This function, now discarded, will be considered again later.

Let us now leave equation 2 in its present form and proceed to the development of the argument which ultimately will lead to the evaluation of the factor $f(I)$.

INFLUENCE OF EXPOSURE

Temperature inversion is a phenomenon met with wherever frost occurs. It is due to the fact that the thermal conductivity of air is so poor that superstrata of different temperature may exist. At night, under ideal frost conditions, the ground surface is cooled by the free radiation of its heat below the temperature of the air immediately adjacent. This surface layer of air becomes chilled through the conduction of its heat to the colder ground surface, while its increased density holds it to the ground; in fact, even is responsible for its motion or drift to the surface point of lowest elevation.

Other conditions being the same, the amount of temperature inversion will be greater following the day with the higher maximum temperature. Also will the degree of temperature inversion be greater on those nights when the values of dew point and relative humidity are relatively low, for it is on such nights that the rate of effective radiation approaches its maximum and minimum temperatures are lowest.

Recent studies in temperature inversion have brought out the fact that very large differences in temperature often exist between hill and valley stations (**8**) (**9**) (**10**) (**11**), or at different elevations on towers erected in cold orchards (**12**). Young (**9**) has found a site in southern California where the minimum temperature at a hillside station less than one-half mile distant and 225 feet higher than a base station was on the average nearly 17° F. higher than at the base station, with extreme differences as great as 28° F. and as small as 8° F.

Let us assume that temperature formulas were to be constructed for each of these stations, using equation 2. It is evident that the absolute humidity at both stations would be subject only to minute local variations and that the only practical difference in the formulas would be in the values assigned to the factor $f(I)$. The adiabatic temperature difference is here neglected owing to its doubtful existence and its small theoretical value. For the base station, $f(I)=0$, and would vanish. For the hill station, $f(I)=+17°$, with extreme errors of application ranging from $-9°$ to $+11°$, or more than sufficient to nullify any accuracy to be obtained by computation with the other factors.

In every air drainage system there is some one point where the slowly moving air first gathers to form the nucleus of the pool of cold air that later covers the valley lowlands. Such a point is called a key point and the temperature station at the key point is called a key station. It is obvious that the temperature at the key point is unaffected by the degree of prevailing temperature inversion, since it is the point from which the temperature inversions are measured and the one point where the degree of temperature inversion is always zero. Thus the value of the factor $f(I)$ can be made to vary more or less at will merely by moving from one point to another, and can be made to vanish at the key point.

The general equation for minimum temperature under ideal frost conditions at the key station can now be written:

$$y=f(d)+f(h). \tag{3}$$

FACTORS DIFFICULT OF MATHEMATICAL EXPRESSION

The ideal frost conditions occur but rarely in nature. Other factors are required if Equation 3 is to be made applicable to all nights.

1. *Effects due to changing weather conditions.*—If warmer or colder air were brought in from surrounding regions by the general atmospheric circulation, or if the absolute humidity were changed by this wind movement, it is obvious that the minimum temperature would be affected.

2. *Effects due to mechanical action of night winds.*—Such winds are of frequent occurrence. They disturb the air drainage, even to the extent of shifting the key point; raise the surface temperature by mixing the warmer air aloft with the colder air near the ground (**13**); and sometimes completely prevent the inversion of temperature.

3. *Effects due to cloudiness.*—Clouds of any type composed of water droplets interfere with free radiation, but dense lower clouds have greater effect than any other kind (**14**) (**15**). High thin clouds, composed of ice crystals, have little or no effect on the rate of cooling through radiation.

Any one of the factors just named could have sufficient influence by itself to prevent, to a large extent, the usual nocturnal fall in temperature, by disrupting the normal processes under which the surface temperature is made to fall. Many nights which would prove damagingly cold under ideal frost conditions are characterized by temperatures well above the danger point, due to the action of winds. Clouds overspreading the sky in the latter portion of the night have been responsible for an abatement of threatened frost on many occasions, and fog often prevents it. Changes in absolute humidity during the night sometimes alter the rate of free radiation and cause minimum temperatures other than would have been experienced without such change.

These factors are difficult of mathematical expression. Their effects can be approximated from a study of current weather maps, and esoterically interpreted in terms of the number of degrees by which the free radiation minimum temperature formula estimate must be modified. Minimum temperature formulas, no matter how accurate they may be on nights when the ideal frost condition prevails, can not be used indiscriminately; nor has it been found possible to construct minimum temperature formulas of any practical value for all nights. The best solution to the problem of minimum temperature forecasting is to express mathematically the factors that

can be so expressed and approximate the others. The minimum temperature formula is thus a means to an end and not an end in itself.

SELECTION OF DATA

Theoretically only the temperature data obtained on radiation nights should be used in the construction of the minimum temperature formula. In actual practice, however, it is found that there are very few nights during the frost season when ideal radiation conditions obtain. On many nights when frost gives real concern there is more or less wind or cloudiness or both over a portion of the night. But the fact remains that on most nights when frost does occur, ideal radiation conditions are present during the greater portion of the night, and under these conditions the minimum temperature closely approximates that which would have been experienced under ideal frost conditions.

It would appear that when the normal fall in temperature is interrupted by adverse radiation conditions of a local nature, such as intermittent breezes or occasional cloudiness, with a return to the ideal conditions after a short interval, the fall in temperature is accelerated until the effects of the temporary temperature rise are obliterated and the normal fall is again resumed. There is no ready way of explaining this phenomenon except by considering that the nonradiation conditions are intensely local during any given interval and that the great system of air drainage is not permanently affected to any material extent.

Data from which minimum temperature formulas are to be derived should include all nights when the minima at the key station were 32° F. or lower, with the occasional rejection of data obtained on cold nights when radiation conditions did not preponderate, and some additional data taken under ideal frost conditions even though the key station minima were above freezing.

POINTS OF SIMILARITY IN FORMULAS

It is a point in common with all minimum temperature formulas that after the factors to be correlated have been selected, the actual construction of the formula is patterned after the same general method. A "dot chart" is prepared by plotting one factor against another. The problem is then concerned with a determination of the line of "best fit" (**17**) to the data on the dot chart. The finished formula itself is simply the mathematical expression of this line.

The construction of the formula from data accumulated over a number of years presupposes an average condition in the moisture content of the surface soil. That the extreme condition in soil moisture is an important factor in minimum temperature forecasting is quite evident from the practical application of the hygrometric formula during periods of extreme drought or immediately after periods of heavy rainfall. When the surface soil is abnormally dry, minimum temperatures lower by from 1° F. to 3° F. than the hygrometric formula estimate usually are experienced. When the surface soil is thoroughly soaked with rain, the minimum temperature experienced usually is from 1° F. to 3° F. higher than the indicated minimum temperature by formula. By judicious use of this principle it often is possible to improve upon the accuracy of the formula estimate.

TEMPERATURE FORMULAS SUGGESTED

Many investigators have suggested from time to time empirical formulas designed to evaluate the minimum temperature from factors which can be assigned definite values in the late afternoon or early evening. These formulas can be placed, roughly, into three mathematical groups:

Group 1. $y=f\ (T)$.
Group 2. $y=f\ (d)$.
Group 3. $y=f\ (d)+f\ (h)$.

It is now proposed to deal with each group by itself, first listing by numbered paragraphs the various formulas as they have been proposed by their originators, and later critically discussing each formula in a paragraph numbered to correspond. The following mathematical conventions will be used throughout the remainder of the paper:

y is the minimum temperature,
d is the temperature of the dew point at an afternoon observation,
h is the relative humidity coincident with d,
n is a number deduced from study of data,
V_d is a variable depending on d, and,
V_h is a variable depending on h.

FORMULAS IN GROUP 1

1. "Median-hour" relationship suggested by Beals (**18**). The average time of occurrence of the temperature halfway between the maximum and minimum temperatures is found. The temperature reading taken at the time of the median is then subtracted from the maximum temperature and the remainder is used to indicate the approximate fall that will occur between the median and minimum temperatures.

2. "Post-median-hour" relationship suggested by Thomas (**19**). The number of degrees in temperature between the maximum and the temperature registered at 10 p. m. is considered to be two-thirds of the fall between maximum and minimum.

3. "Pre-median-hour" method originated by Alter (**21**). The trend of temperature fall in the early evening is used by the forecaster to predict the median-hour temperature by extrapolation, and thus to arrive at an earlier approximation of minimum temperature by the true median-hour method.

4. "Maximum-minimum" relationship proposed by Nichols (**22**) (**23**). The minimum temperature is considered to be a direct function of the preceding maximum temperature, so that when the maximum temperature is known, the minimum temperature can be determined.

5. "Daily temperature range" method formulated by Smith (**26**). The average, greatest, and least daily temperature range is computed by semimonthly periods, and the values used in minimum temperature forecasting after the maximum temperature is known.

DISCUSSION OF FORMULAS IN GROUP 1

1. The median-hour formula is based upon the general principle of assumed harmonic relationship between time and temperature under ideal frost conditions. Unless a special development of the principle is made, however, there is one type of night that occurs rather frequently under ideal frost conditions wherein the median-hour

formula would not apply. This type of night occurs when the dew-point temperature is reached, or closely approached, near the hour of the median. How long the air temperature will then remain nearly stationary, or continue to fall at a constantly decreasing rate, or whether the air temperature will fall lower than the dew point at all, are matters not related to the rate of effective radiation preceding the median hour. Since there is no evidence of any such special development having been made, it is probable that some of the inaccuracies in the application of the median-hour formula are due to this necessity for segregation of data.

Many investigators who have tried to utilize this type of formula have reported unsatisfactory results. It would appear that the median-hour formula is open to some serious practical objections.

To give satisfactory results any type of minimum-temperature formula must have some application on nights when ideal frost conditions do not obtain at all times between sunset and sunrise. Many cold nights are preceded by cloudy afternoons, as frost is observed frequently following the passage of a cyclone, and the time of occurrence of the maximum temperature is affected to such an extent as to impair the application of the median-hour method.

A rapid drop in air temperature in the early part of the night is quite often followed, in many districts, by local winds which cause fluctuating temperatures over short intervals. In fact, in some places, the topography is such that the fall in temperature must be considered as a causative agent in the production of local winds, as, for example, the well-known phenomenon of mountain and valley winds. The median-hour method stakes all on the air temperature at a certain instant, yet the temperature at this instant is often affected by local conditions.

The time of occurrence of the median hour in many sections of the country is so late that it is impracticable to use the formula in the preparation of forecasts.

Changes in absolute humidity near the time of the median will seriously impair the application of this method by changing the rate of effective radiation after the median temperature occurs. Such absolute humidity changes are frequently observed in mountainous country due to reversal of winds aloft under special conditions.

2. The post-median-hour relationship is open to the same objections as those just listed for the median-hour formula, except that the lateness of the zero hour detracts even more from its practical use.

3. The pre-median-hour method also is subject to the same criticisms. The method was originally devised to overcome one of the principal objections to the median-hour formula, namely, the delay in the preparation of the minimum temperature forecast while waiting for the median hour to be reached. It is evident that the chances for error in the approximation of the median-hour temperature would make the forecasts by this method subject to more risk than by the median-hour method itself, without any hope of attaining greater accuracy in the predictions.

4. The maximum-minimum temperature formula simply states that with a given maximum a certain range will ensue and a given minimum be reached. When it is considered that with any given maximum temperature a variety of values for absolute humidity are observed in practice, it is evident that differences in the rates of free radiation of the earth's heat will occur during different nights and consequently a variety of minimum temperatures are experienced. These formulas, then, appear to be faulty at their source.

Nichols, who is the chief proponent of the maximum-minimum type of formula, in the endeavor to improve the usefulness of the basic relationship, has extended the application by a complex system of type classification wherein five classes of weather conditions are recognized **(24)**. He concludes, however, that the relationship is inferior to the hygrometric correlation and that "* * * greater inaccuracy is likely to result from incorrect classification than from inaccuracies in the formulas when correctly applied" **(25)**.

5. The daily temperature range method is a variation of the maximum-minimum method previously discussed and is open to the same objections.

From a purely abstract consideration of values inherent in temperature formulas of the form $y=f(T)$ it would seem that in so far as accuracy is concerned they would range in the following order:

1. Postmedian-hour formulas.
2. Median-hour formulas.
3. Premedian-hour formulas.
4. Maximum-minimum formulas.

The postmedian-hour formulas would be the most accurate and the maximum-minimum formulas the least accurate, owing to the variation in the time to elapse before the occurrence of the minimum temperature after the determination of T. A forecast prepared one or two hours in advance of an event certainly should be expected to have greater accuracy than a forecast prepared 12 to 14 hours in advance.

In actual practice, however, the minimum temperature forecast must be made and disseminated long before the time of occurrence of the median hour in most parts of the country. This fact alone excludes from serious consideration all the formulas of this group except the maximum-minimum and certain of the premedian-hour formulas. Thus, the only formulas of the form $y=f(T)$ available for practical use are the least accurate of the group.

FORMULAS IN GROUP 2

1. "Evening dew-point" relationship proposed by Humphreys **(3)**: The temperature is assumed not to fall below the value of the coincident dew-point temperature, which, for forecasting purposes, is considered to be closely the same as the evening dew point. In other words, the minimum temperature is determined by the value of the evening dew point.

2. "Wet-bulb" method originated by Ångström **(27)**: A constant is subtracted from the wet-bulb temperature at sunset and the remainder indicates the ensuing minimum temperature.

3. "Wet-bulb-minimum temperature" method proposed by Keyser **(28)**: The average difference between the wet-bulb temperature at 5:00 p. m., and the ensuing minimum temperature is found. The 5:00 p. m. wet-bulb temperature, when decreased by the amount of average difference, is the estimated minimum temperature.

4. "Depression of the evening dew-point" method tried by Smith **(29)**: The difference obtained by subtracting the evening dew-point temperature from the coincident air temperature at an evening observation is used in correlation with the difference obtained by subtracting the evening dew-point temperature from the ensuing minimum temperature. The relationship thus determined enables the minimum temperature to be computed from evening observational data.

5. "Depression of the dew point below maximum temperature," method originated by Nichols (**31**): The difference obtained by subtracting the temperature of the evening dew point from the preceding maximum temperature is argued against the ensuing range in temperature between maximum and minimum. The relationship determined enables the minimum temperature to be computed from the evening observational data.

DISCUSSION OF FORMULAS IN GROUP 2

1. Soon after its initial formal statement, Smith (**33**) provided a refutation based on observational fact of the principle inferred in the evening dew-point formula, namely that the minimum temperature would not be lower than the temperature of the evening dew point. Other investigators (**11**) and the meteorological records taken in connection with fruit-frost work establish the soundness of Smith's argument. Generally speaking, the relationship can not be consistently demonstrated except for elevated stations, well placed in the inversion layer. At key stations the minimum temperature often is lower than the evening dew point by more than 8° to 10° F., with occasional extremes of more than 20° F. The formula, therefore, is inherently faulty.

2. The wet-bulb temperature is determined when the coincident dry-bulb temperature and the dew point are known. Under any given condition its value is greatest when the relative humidity is 100 per cent, for it is then that the wet and dry bulb temperatures coincide, and its value becomes progressively less with decreasing relative humidity. In other words, wet-bulb temperatures and relative humidity change in direct ratio with unchanging dew point.

Assume the dew point to remain constant. The wet-bulb temperature can now be made to vary by causing that of the dry bulb to change. If the difference between the minimum temperature and the wet-bulb readings at an evening observation is always to be a constant, then we are justified in assuming that the difference between the minimum and the dew point, which remains fixed, will likewise be a constant *for all values of relative humidity.*

But when the dew point is fixed, Equation 3 assures us that the variation of the minimum temperature from the evening dew point depends upon the relative humidity, or,

$$y-d=f(h)$$

and investigators are universally agreed that the right-hand member of this equation is not a constant. The hygrometric dot charts that comprise Supplement 16, Monthly Weather Review, offer ample proof of this contention.

During the winter of 1922-23, Dague experimented with Ångström's formula in a district in southern California and found in this season that the variation of the minimum temperature from the evening wet-bulb temperature was not a constant, but had values ranging from +12 F. to +23° F. (**35**).

We conclude that Ångström's wet-bulb formula is fundamentally in error and must be rejected.

3. This formula is of the same order as the one previously discussed. Keyser, the proposer himself, admits its inferiority (**28**).

4. Some rather unsatisfactory attempts have been made to correlate the depression of the evening dew point with the variation of the minimum temperature from the evening dew point (**29**). The difficulty with the relationship here expressed lies in the fact that when the depression of the evening dew point is computed a pure number is obtained which may be the same for widely differing values of absolute humidity or air temperature. Thus, for example, the number 21, which here is taken to represent the difference between the air temperature and dew-point temperature at an evening observation, may occur under any condition of absolute humidity, as the air temperature may vary in such manner that a differential of 21 always is maintained; or the same number 21 may be obtained with any value of air temperature, depending on the absolute humidity. The appearance of the differential 21, therefore, is no indication whatever of the amount of moisture in the air. Many widely differing rates of free radiation, consequently with widely differing minimum temperatures, can occur with any designated differential.

5. The depression of the evening dew-point temperature below the maximum temperature formula simply states that a certain range in temperature will ensue following the occurrence of a certain differential between maximum temperature and evening dew point. But the temperature difference between afternoon maximum and evening dew point is not a measure of the absolute humidity, for these latter are independent factors and almost any difference can obtain between them when one or the other is regarded as being fixed. With any designated differential between afternoon maximum temperature and evening dewpoint, therefore, a variety of values for absolute humidity may exist, and with them, a variety of nocturnal temperature ranges instead of but one.

FORMULAS IN GROUP 3

Strictly speaking, there has been but one fundamental relationship of the form $y=f(d)+f(h)$ set forth by investigators, although at first glance several different formulas seem to appear. The difference lies not in the basic relationship itself but in the methods used to express this relationship mathematically. The difference in formulas, therefore, is one of form rather than of concept.

1. "Hygrometric" method. The fundamental concept underlying all hygrometric formulas in this group is that the ensuing minimum temperature will be greater or less than the evening dew-point temperature by an amount depending on the relative humidity. In this method the difference obtained by subtracting the evening dew-point temperature from the minimum temperature is argued against the evening relative humidity. The relationship is used to predict the minimum temperature from evening observational data.

DISCUSSION OF FORMULAS IN GROUP 3

1. The hygrometric relationship is the only one so far proposed that conforms strictly to equation 3, evolved for predicting the minimum temperature at the key station under ideal frost conditions. It is to be expected that the hygrometric formulas should be the most satisfactory. The greater part of the published literature on minimum temperature formulas has to deal with those based on this relationship, and the consensus of investigators is almost unaminous in awarding to them the wreath of superiority. These formulas, then, deserve more than a passing glance.

The hygrometric relationship was first proposed by Donnel in 1910, while working on Boise, Idaho, frost

records (36) (20) (37). Donnel developed a hygrometric formula for Boise based on psychrometric observations taken at 6:00 p. m. through the assumption that the line of best fit to the hygrometric dot chart was a straight line whose equation is of the form

$$y=d-\frac{h-n_1}{n_2}.$$

So far as known, no extended practical use in forecasting was ever made of this equation and it was regarded as unsatisfactory except for a certain narrow range of relative humidity and dew point, where fairly consistent results were obtained.

In August, 1917, Smith published in the Monthly Weather Review the results of an investigation of the hygrometric relationship based on fruit-frost work in Ohio since 1915 (34). He followed a different line of attack than Donnel and determined from the correlation coefficient the probable existence of a linear relationship, later calculating the straight-line formula by the method of least squares (38) and expressing the hygrometric formula in the following convention:

$$Y=a-bR$$

where

Y is the difference between the minimum temperature and the evening dew point, or $Y=y-d$;

R the evening relative humidity, or $R=h$; and

a and b are two numbers deduced from study of data, or

$a=n_1/n_2$ and $b=1/n_2$.

Marvin has already demonstrated the mathematical identity of these original Smith and Donnel equations (36). In this case both investigators arrived at exactly the same place by following different routes; one of which was considerably longer and more difficult than the other.

In the spring of 1917, Young, while engaged on fruit-frost work at Medford, Oreg., investigated the hygrometric formula proposed by Donnel for Boise (39). He used data taken at 5:00 p. m. instead of 6:00 p. m., and found that the original Donnel equation gave fairly accurate results at Medford on cold nights when the sky was cloudy at observation, but indicated values too high when the weather at observation was partly cloudy or clear. This defect was remedied by writing separate equations for these two classes of nights. In effect, this amounted to subtracting 2½° F. and 5° F., respectively, from the original formula to make it applicable on partly cloudy and clear nights.

In using these equations it was found that when the 5:00 p. m. dew point was below 30° F. or above 40° F., the minimum temperature indicated by the formula consistently varied from the actual minimum temperature by an amount that was nearly constant with the same dew point. Also, when the relative humidity at 5:00 p. m. was above 67 per cent the formula needed revision upward by an amount depending on the relative humidity. Thus was developed the device called the "method of arbitrary corrections," by means of which the basic straight-line formula was made to take on an irregular *curvilinear* form. Later, the results of this investigation were published in Supplement 16 (16). Young expressed his formula after this form:

$$y=d-\frac{h-n}{4}+V_d+V_h.$$

He, therefore, was the first to use in actual minimum temperature forecasting a hydrometric formula which expressed a curved line of best fit to the data from which it was constructed.

In July, 1919, Smith published in Supplement 16 a method for fitting parabolic curves to hygrometric dot charts after the Marvin "star-point" system (17) and the mathematical expression of hygrometric formulas in the form of parabolic equations:

$$y-d=n_1+n_2h+n_3h^2.$$

Nichols found that a rectilinear hyperbola would, in some cases, give better correlation than the parabolic type curve (32).

Nichols (25) and Keyser (40) brought forward the idea that dot-chart data in all cases might not best be represented by any of the simpler mathematical curves and suggested the extension of the "star-point" system to the

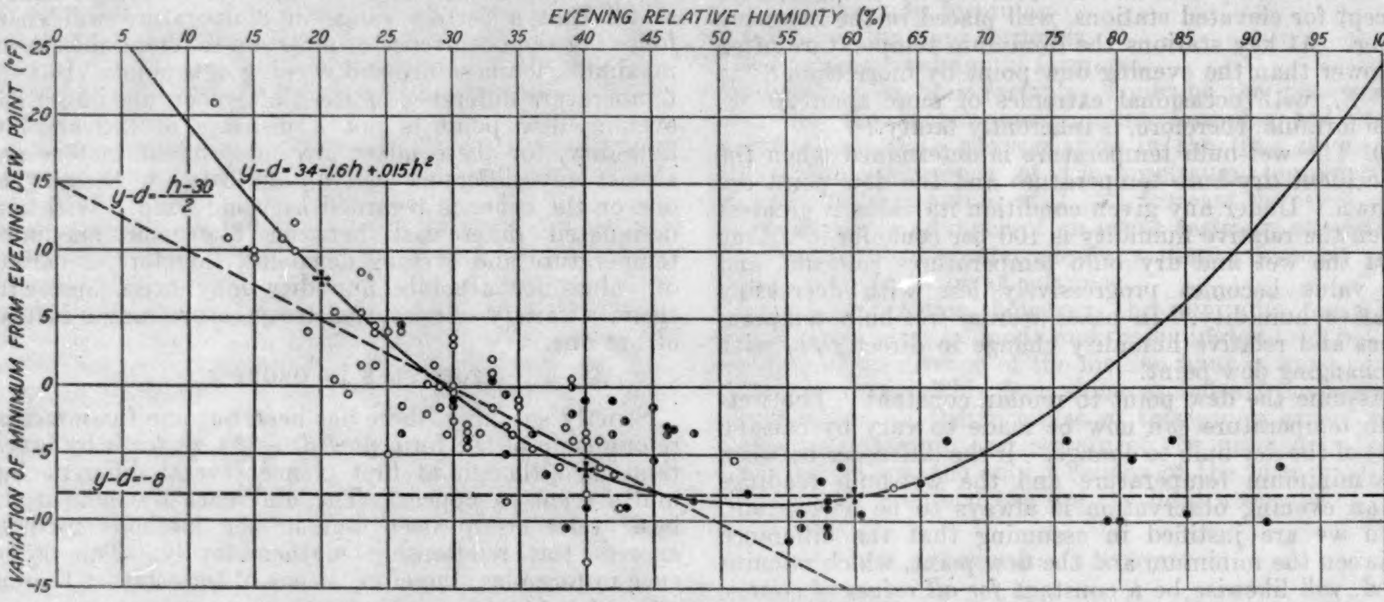


FIGURE 1.—Hygrometric dot chart for key station at Medford, Oreg., based on spring frost records from 1917 to 1928. State of weather at observation is shown by symbols. The parabolic curve of formula 1 and the straight lines of formula 3 have been plotted on the chart

production of a curve drawn by eye alone. This free-hand curve could than be used directly from the dot chart without recourse to further mathematical methods.

Since these various hygrometric formulas and forecasting methods are all based on the fundamental relationship expressed in Equation 3, it is impossible to make selection of the best one of the group without some investigation into the relative merits of all. Perhaps the best method of making this comparison would be to develop all the formulas from the same data, and then to determine the *relative* worth by applying the fromulas back on the data from which they were derived. If one formula were superior to another this method surely would bring it to attention.

An intensive study of hygrometric data taken at the Medford, Oreg., key station during the spring frost seasons 1917 to 1928, inclusive, is now proposed. In this study only the finished dot charts, formulas, and frequency diagrams of the investigation will be presented.

Reference is made to the hygrometric dot chart shown in Figure 1 from which a number of formulas are now to be derived. On this chart are plotted data secured on 106 nights at the Medford, Oreg., key station during the spring seasons over a 12-year interval. The data have been selected to include all nights when the minimum temperature fell to 34° F. or lower, provided the sky was clear over the greater portion of the night. Symbols on the chart show the state of the sky at the time of observation. Naturally, a large portion of the data were taken on nights not ideal for free radiation and the wide scattering of the dots may be attributed to this reason. The rejection of data on nights when the sky did not clear until after midnight would result in a much more compact arrangement of the dots. This was not done because it was desired to deal with the situation under conditions as they occur in actual practice.

SMITH FORMULA

The first formula to be considered is the parabolic type patterned after the Smith method. Three "Star points" have been selected as indicated on Figure 1; one point for each 35 dots. The hygrometric formula is expressed:

$$y-d=34-1.6h+.015h^2. \qquad \text{Formula 1.}$$

and its position shown on the dot chart. (See figure 1.) When this formula is applied back on the data from which it was derived the results shown in the frequency diagram are obtained. (See figure 3.)

If, now, the method of arbitrary corrections be applied to the Smith formula as a base, the new formula becomes

$$y-d=34-1.6h+.015h^2+V_d+V_h. \qquad \text{Formula 2.}$$

with values for the variables shown in the table below:

d	V_d	h	V_h
7° to 24°	+2	12% to 21%	− 2
26° and 27°	+1½	22% to 25%	− 2
28° to 30°	0	26% to 31%	− 1
31°	+1½	32% to 34%	+ ½
32° and 33°	+1	35% to 39%	+ 1½
34°	0	40% to 42%	+ 1
35° and 36°	−1½	43% to 51%	+ 3½
37° and 38°	− ½	52% to 59%	0
39° and 40°	−1½	60% to 76%	− ½
41° to 44°	−3	77% to 85%	−11½
		86% to 92%	−21

When Formula 2 is applied back to the original data the results shown in the frequency diagram in Figure 4 are obtained.

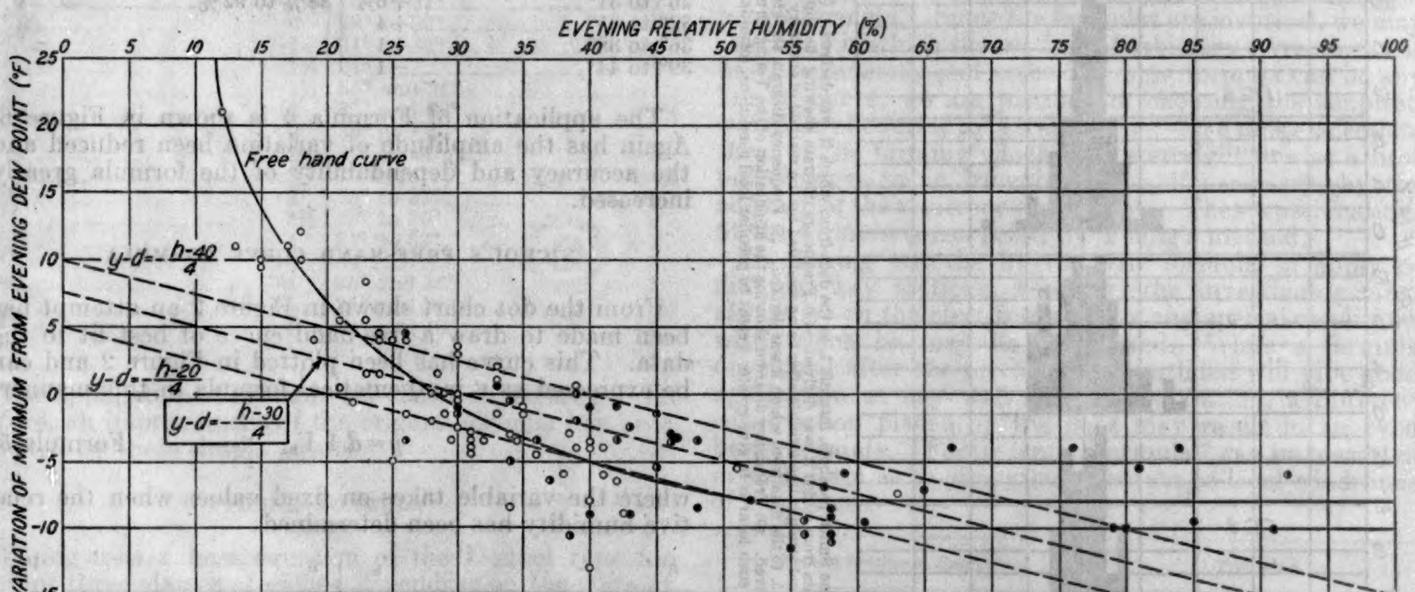


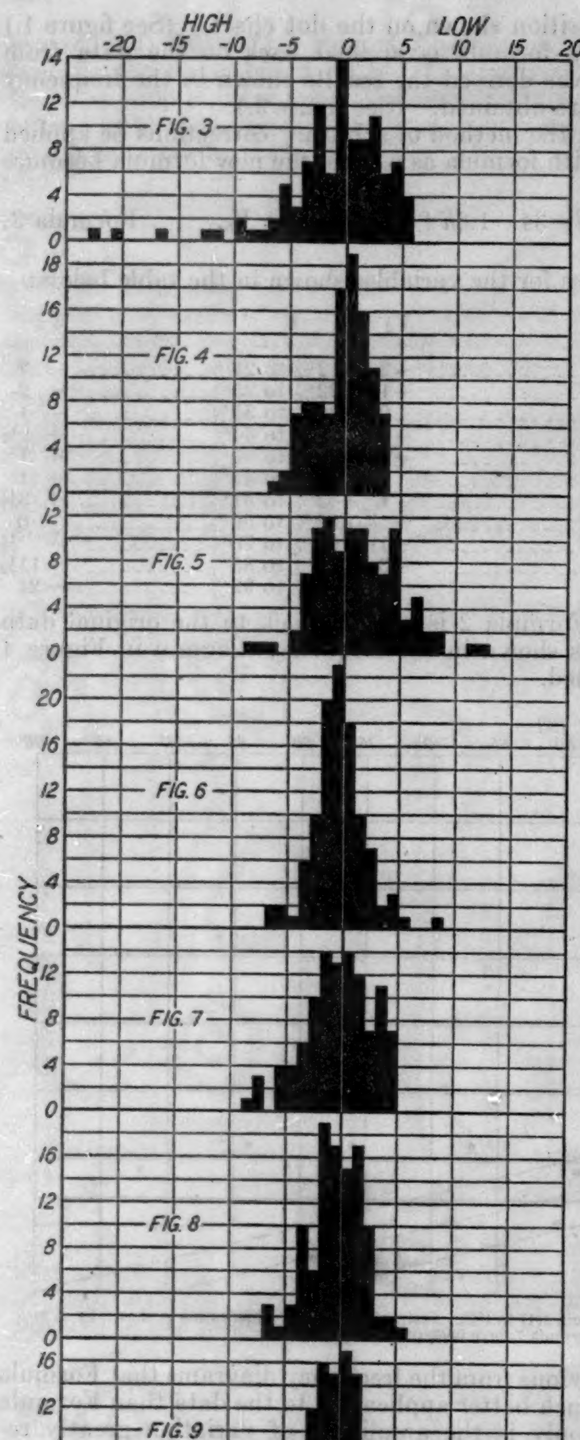
FIGURE 2.—Hygrometric dot chart for key station at Medford, Oreg., based on spring frost records from 1917 to 1928. State of weather at observation is shown by symbols. The free-hand curve of formula 5 and the basic straight lines of formula 7 have been plotted on the chart

It is obvious from the frequency diagrams that Formula 2 gives much better application to the data than Formula 1. Not only is the amplitude of variation greatly reduced, but also the accuracy is materially increased.

DONNEL FORMULA

Examination of the dot chart in Figure 1 shows at once that it would not be possible to select a single straight line to represent the data faithfully. Accordingly a subdivision of the data has been made in order to apply the Donnel method.

State of weather at observation	Relative humidity at observation	Formula 3
Clear	44% or less	$y=d-\frac{h-30}{2}$
Partly cloudy or cloudy.	Any value	$y=d-8$
Clear	45% or more	$y=d-8$



FIGURES 3-10.—(3) Frequency diagram showing the application of the the Smith parabola, formula 1, to the data from which it was derived. (4) Frequency diagram showing the application of the Smith parabola after being modified by the method of arbitrary corrections, formula 2, to the data from which it was derived. (5) Frequency diagram showing the application of the Donnel straight-line formula, formula 3, to the data from which it was derived. (6) Frequency diagram showing the application of the Donnel straight-line formula after being modified by the method of arbitrary corrections, formula 4, to the data from which it was derived. (7) Frequency diagram showing the application of the Nichols free-hand curve formula 5, to the data from which it was derived. (8) Frequency diagram showing the application of the Nichols free-hand curve after being modified by the method of arbitrary corrections, formula 6, to the data from which it was derived. (9) Frequency diagram showing the application of the Young formula, formula 7, to the data from which it was derived. (10) Frequency diagram showing the application of the Young formula after being written in such form as to give greater weight to peculiar local conditions, formula 8, to the data from which it was derived

The position of these lines is shown in Figure 1, and the application of the formula is presented in the frequency diagram in Figure 5.

Applying the method of arbitrary corrections to Formula 3 changes it to this form:

State of weather at observation	Relative humidity at observation	Formula 4
Clear	44% or less	$y=d-\frac{h-30}{2}+V_d+V_h$
Partly cloudy or cloudy.	Any value	$y=d-8+V_{d1}+V_{h1}$.
Clear	45% or higher	

where the variables take on the following values:

d	V_d	h	V_h
7° to 24°	+4½	12% to 30%	−1
26° to 29°	+1½	31% to 34%	0
30° to 35°	0	35% to 44%	+1½
36° to 43°	−3		

d	V_{d1}	h	V_{h1}
26° to 31°	+6½	26% to 37%	+1
32° to 35°	+4	38% to 92%	0
36° to 38°	+1		
39° to 44°	−1		

The application of Formula 4 is shown in Figure 6. Again has the amplitude of variation been reduced and the accuracy and dependability of the formula greatly increased.

NICHOL'S FREE-HAND CURVE FORMULA

From the dot chart shown in Figure 2 an attempt has been made to draw a free-hand curve of best fit to the data. This curve has been plotted in Figure 2 and can be expressed as a mathematical formula in this manner:

$$y=d+V_h. \qquad \text{Formula 5.}$$

where the variable takes on fixed values when the relative humidity has been determined:

h	V_h	h	V_h
12%	+21	33%	−2½
13%	+18	34%	−3
14%	+16	35%	−3
15%	+14	36%	−3½
16%	+12½	37%	−4
17%	+11	38%	−4
18%	+9½	39%	−4½
19%	+8	40%	−5
20%	+7	41%	−5
21%	+6	42%	−5½
22%	+5	43%	−6
23%	+4	44%	−6
24%	+3	45%	−6
25%	+2½	46%	−6½
26%	+1½	47%	−7
27%	+1	48%	−7
28%	0	49%	−7
29%	−½	50%	−7½
30%	−1	51%	−7½
31%	−1½	52% to	
32%	−2	100%	−8

The free hand curve closely resembles the Smith parabola, Formula 1, for relative humidities between 10 per cent and 52 per cent, but becomes the same as the Donnel formula, Formula 3, for relative humidities

above 52 per cent. It is in reality a combination of the better parts of both Formula 1 and Formula 3 and the frequency diagram showing its application assures us that it is better than either the Smith of the Donnel formulas taken separately. See Figure 7.

The addition of the method of arbitrary corrections to Formula 5 changes it to this form:

$$y = d + V_d + V_h. \qquad \text{Formula 6.}$$

where the variables take on values as follows:

h	V_h	h	V_h
12%	+18½	43%	−6
13%	+15½	44%	−6
14%	+13½	45%	−6
15%	+11½	46%	−6½
16%	+10	47%	−7
17%	+8½	48%	−7
18%	+7	49%	−7
19%	+5½	50%	−7½
20%	+4½	51%	−7½
21%	+3½	52% to 100%	−7
22%	+4	***d***	V_d
23%	+3		
24%	+2		
25%	+1½	7° to 24°	+ ½
26%	+½	25° to 27°	+1
27%	0	28° to 30°	0
28%	−1	31° to 33°	+2
29%	−1½	34°	0
30%	−1½	35° and 36°	−1
31%	−2	37° and 38°	− ½
32%	−2	39° and 40°	−1
33%	−2½	41° to 44°	−2
34%	−3	7° to 24°	+ ½
35%	−3	25° to 27°	+1
36%	−3½	28° to 30°	0
37%	−4	31° to 33°	+2
38%	−4	34°	0
39%	−4½	35° and 36°	−1
40%	−5	37° and 38°	− ½
41%	−5	39° and 40°	−1
42%	−5½	41° to 44°	−2

The application of Formula 6 is shown in Figure 8. As before, an improvement of the original formula has been effected by these simple means.

YOUNG FORMULA

Young uses a base equation of the Donnel type for each of three classes of nights, depending on the state of weather at observation. The method of arbitrary corrections is applied to the formula as a whole. The base equations in this case are plotted in Figure 2 and the hygrometric formula expressed:

State of weather at observation	Formula 7
Clear	$y=d-\frac{h-20}{4}+V_d+V_h.$
Partly cloudy	$y=d-\frac{h-30}{4}+V_d+V_h.$
Cloudy	$y=d-\frac{h-40}{4}+V_d+V_h.$

d	V_d	h	V_h
7° to 24°	+9	12% to 21%	+1
25° to 30°	+2	22% to 25%	+½
31° to 34°	+1½	26% to 39%	−½
35° to 38°	−1½	40% to 59%	−1
39° and 40°	−3	60% to 79%	+2
41° to 44°	−4½	80% to 92%	+5½

The application of this formula is shown in Figure 9. It is a fact worth noting that the amplitude of variation in Figure 9, roughly from 5° too high to 5° too low, is nearly the same as shown in Figures 4, 6, and 8. The types of frequency curves in these figures, to, are not, entirely dissimilar. If the mass of data were greater the similarity undoubtedly would be more pronounced.

Assuming that the data on the dot chart have but one correct interpretation, only one line of best fit can be drawn. The evidence in this case points strongly to the idea that the line of best fit is irregular, since the addition of the arbitrary corrections to any base formula results in an irregular line unless the base formula itself is the line of best fit, in which case the corrections vanish. In each case here considered the irregular line formula produced by the corrections gives better application to the data than the regular base formula by itself. And in each case the irregular line formula when applied to the original data produces the same general type of frequency curve, regardless of the type of base formula used in the derivation. We conclude, therefore, that the addition of the method of arbitrary corrections to *any* base line or curve will produce the same irregular line of best fit to any hygrometric dot chart.

We are now in position to select the best type of hygrometric formula. Since the formulas are identical, we may select any in which the method of arbitrary corrections has been considered, and since the base formula can be any line or curve, we are justified in choosing the simplest, which is, of course, the straight line. We make selection, then, of the formula which uses a straight line as a base but changes to an irregular curve, if necessary, by the addition of the arbitrary corrections. These specifications fit the formula constructed by Young's method.

In seeking out the hygrometric formula to apply to different key stations, however, the investigator must always be on the alert to recognize any special conditions with which he may be confronted. While a formula developed after the methods just outlined will give good application at any well chosen key station, a different construction placed on the data may result in an even better formula. For instance, Formula 7 can be rewritten in such form as to give greater weight to local conditions of cloudiness.

State of weather at observation	Formula 8
Clear	$y=d-\frac{h-20}{4}+V_{d1}+V_{h1}.$
Partly cloudy	$y=d-\frac{h-30}{4}+V_{d2}+V_{h2}.$
Cloudy	$y=d-\frac{h-40}{4}+V_{d3}+V_{h3}.$

d	V_{d1}	h	V_{h1}
7° to 24°	+10	12% to 21%	0
25° to 29°	+ 3½	22% to 26%	− ½
30° to 35°	+ 2	27% to 30%	−1
36° to 43°	− 2	31% to 39%	+ ½
		40% to 51%	−1

d	V_{d2}	h	V_{h2}
26° to 31°	+ ½	26% to 38%	−2½
32° to 42°	− 2	39% to 63%	+1

d	V_{d3}	h	V_{h3}
26° to 37°	+ 1	30% to 52%	−3
37° to 39°	− 1½	53% to 65%	− ½
40° to 44°	− 4	66% to 91%	+4

The frequency diagram in Figure 10 giving the application of this formula shows that the amplitude of variation has been reduced to 3° for 103 of the 106 cases of frost used to construct the formula.

METHOD OF CONSTRUCTING YOUNG FORMULAS

Since it is a conclusion of this study that the Young type of formula is superior to the others, it may be well to state briefly, step by step, an easy method of developing this type of formula.

1. Construct a dot chart after the methods outlined by Smith (**30**). This is the initial step in the construction of any minimum temperature formula. Either make a separate chart for clear, partly cloudy, and cloudy nights, or better, place all data on one chart, denoting segregation by use of inks of different color. A small index number keyed to the original data sheet is placed near each dot for identification purposes.

2. Draw a straight line on the chart to represent, as nearly as a straight line may, the data. To simplify the formula, care should be taken to select a line capable of whole number expression, even though the position of the true line is shifted slightly. Draw a line for each class of data if one line will not represent the whole.

3. Express this line in the form:

$$y=d-\frac{h-n_1}{n_2}$$

where n_1 is the number measured on the horizontal relative humidity scale where the line intersects the X-axis, or zero line of departure, and, n_2 is the number of units measured by projecting the line on the horizontal relative humidity scale, that the line changes in order to pass through one unit of variation by projection on the vertical scale of departures.

4. To facilitate the calculation of the arbitrary corrections, the data for each day should be written on a card. The example shown below indicates the data to be considered and the method of preparing the cards. The headings, of course, can be omitted.

Index No.	Evening dew point	Evening relative humidity	Minimum temperature	State of weather
116	30. 5°	76%	28. 4	Cloudy. Cleared 9:30 p. m.

5. Using the straight line formula just calculated, go through the cards and calculate the formula minimum temperature. Find the departure between this and the actual minimum temperature.

6. Now arrange the cards in the order of increasing relative humidity. At more or less regular intervals—say, about 10 cards—calculate the average departure of the formula minimum temperature estimate from the actual minimum temperature. This is the arbitrary correction to be applied to the formula over the range of relative humidity indicated. Apply this correction to the original formula estimate and calculate the new departure.

7. After the relative humidity corrections have been determined and applied, arrange the cards in the order of increasing dew point. Repeat the process just outlined, thus determining the arbitrary correction to be applied to the formula over the range of dew point indicated.

CONCLUSIONS

Under ideal frost conditions the air temperature at the surface falls during the night, due to the influence of several factors operating simultaneously. The cumulative effects of these several factors can be given mathematical expression, and the minimum temperature closely calculated from hygrometric data taken near sunset on the preceding day, provided care is taken to locate the point for which forecasts are to be prepared with due regard for local topography.

The forecast or key station should be placed as nearly as possible to the point where the cold air that drains from the surrounding slopes first gathers to form the nuceleus of the pool of cold air that covers the lowlands in the morning. By so locating the key station it is possible to avoid entirely the effects due to temperature inversion.

Minimum temperature forecasts by formula are not satisfactory for elevated stations. The errors introduced by the factor of temperature inversion are usually so great as to void any accuracy to be obtained by computation from the other factors. As a general rule it may be stated that the greater the influence of inversion on the minimum temperature at any station, the poorer will be the application of the minimum temperature formula. The formula must have at least as great a variation in application as the difference between the average and extremes of temperature departure due to inversion. Formula construction for an elevated city station is a hopeless task.

As the means of accomplishment are always less important than the ends to be attained, so is the hygrometric formula minimum temperature indications of less importance than the final forecast of minimum temperature, which properly is the result of processes both mathematical and empirical. But the fact remains that the hygrometric formula is an indispensible tool in the hands of the forecaster. Under any of the conditions where frost is formed a skillfully designed hygrometric formula based on key station records over at least a 10-year period offers a purely mathematical method of placing the minimum temperature estimate within 3° F., of the actual to be experienced fully 90 per cent of the time, and in most cases within 6° F., in the remaining 10 per cent. The skill of the forecaster is then directed toward an improvement of the original mathematical estimate within this narrow range.

The forecaster has many things to guide him. In general, it is easy to recognize the cases where the departrue will be in excess of 3° F. This occurs during serious freeze types of weather where the maximum temperature and dew point are unusually low, with an accompaniment of winds of decided force; or else when local winds and cloudiness are to be experienced during a portion of the night. The experience of the previous morning often is at hand. The amount of moisture in the surface soil sometimes offers a dependable means of correction. For the rest, the personal experience of the forecaster in his own particular district, and his personal ability to determine accurately the immediate weather from the current weather chart and translate these indications into the terms of degrees in temperature, is put to test.

The forecaster also must be able to differentiate between the conditions where frost will or will not occur. It is a fact that the majority of nights during the period when frost danger is most acute would be frosty if the sky remained clear and there was no surface wind. The hygrometric formula, being constructed from data taken on cold nights only, invariably indicates this tendency. But all nights during the frost season are not actually frosty. Some are cloudy; some are windy; and some are rainy. It is the forecaster's own job to segregate the nights when the formula will have application. Properly used, the formula will indicate about how low the temperature at the key station will fall under ideal frost conditions, and gives the forecaster a base upon which to build, but it has

nothing but theoretical application on nights when frost is not experienced. The hygrometric formula is not constructed for use on nights like these

Of the many temperature formulas that have been suggested, some are inherently faulty and others have but limited use. The family of temperature formulas based upon the hygrometric relationship has been shown in this paper to be outstandingly superior. It so happens, however, that within this family of hygrometric formulas there is one that maintains a flexibility in construction and accuracy in practical application in a degree not attained by the others. This is the Young formula wherein the basic relationship is linear and close construction given to the data by a series of arbitrary corrections.

Much in useful accuracy is lost if the variables V_d and V_h are not computed. It is not enough to carry the formula development only to the point where the base formulas are determined, for although in such cases there is likely to be excellent correlation between the factors, values usually can be assigned the variables which will result in even closer correlation. The variables provide:

1. For the influence of local topography, and,
2. An empiric evaluation of $f\ (L)$.

If only a short record is available for a key station where it is desired to develop a formula, it will be found that not enough data are at hand from which to construct a satisfactory formula of the Young type. In this case the Smith or Nichols type of formula is recommended, as these formulas lend themselves readily to interpolation. Later, a formula after Young's method can be constructed.

Any of the other formulas in the hygrometric family, when given the same treatment of arbitrary correction as used in Young's formula, have the same flexibility and accuracy. The smooth mathematical line of best fit is altered by the corrections to approach the position of an irregular line of best fit. There is no evidence to support the idea that the data on the dot chart must conform to some standard mathematical line or curve. The evidence, rather, points to the contrary view that, in most cases, the line of best fit is an irregular curve. By the application of the method of arbitrary corrections all the formulas in the hygrometric group are reduced to the same general irregular form regardless of the form of the base formula, whether parabola, hyperbola, free-hand curve, or straight line. In fact, all hygrometric formulas wherein the arbitrary corrections have been considered can be shown to be mathematically identical.

Selection of the Young straight-line formula as the superior formula of the hygrometric group is made for the reason that, since all the formulas when given similar treatment by arbitrary corrections are mathematically identical, it is proper to select the simplest means of accomplishing a desired end.

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The frequency diagram in Figure 10 giving the application of this formula shows that the amplitude of variation has been reduced to 3° for 103 of the 106 cases of frost used to construct the formula.

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Since it is a conclusion of this study that the Young type of formula is superior to the others, it may be well to state briefly, step by step, an easy method of developing this type of formula.

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2. Draw a straight line on the chart to represent, as nearly as a straight line may, the data. To simplify the formula, care should be taken to select a line capable of whole number expression, even though the position of the true line is shifted slightly. Draw a line for each class of data if one line will not represent the whole.

3. Express this line in the form:

$$y=d-\frac{h-n_1}{n_2}$$

where n_1 is the number measured on the horizontal relative humidity scale where the line intersects the X-axis, or zero line of departure, and, n_2 is the number of units measured by projecting the line on the horizontal relative humidity scale, that the line changes in order to pass through one unit of variation by projection on the vertical scale of departures.

4. To facilitate the calculation of the arbitrary corrections, the data for each day should be written on a card. The example shown below indicates the data to be considered and the method of preparing the cards. The headings, of course, can be omitted.

Index No.	Evening dew point	Evening relative humidity	Minimum temperature	State of weather
116	30.5°	76%	28.4	Cloudy. Cleared 9:30 p. m.

5. Using the straight line formula just calculated, go through the cards and calculate the formula minimum temperature. Find the departure between this and the actual minimum temperature.

6. Now arrange the cards in the order of increasing relative humidity. At more or less regular intervals—say, about 10 cards—calculate the average departure of the formula minimum temperature estimate from the actual minimum temperature. This is the arbitrary correction to be applied to the formula over the range of relative humidity indicated. Apply this correction to the original formula estimate and calculate the new departure.

7. After the relative humidity corrections have been determined and applied, arrange the cards in the order of increasing dew point. Repeat the process just outlined, thus determining the arbitrary correction to be applied to the formula over the range of dew point indicated.

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Under ideal frost conditions the air temperature at the surface falls during the night, due to the influence of several factors operating simultaneously. The cumulative effects of these several factors can be given mathematical expression, and the minimum temperature closely calculated from hygrometric data taken near sunset on the preceding day, provided care is taken to locate the point for which forecasts are to be prepared with due regard for local topography.

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Minimum temperature forecasts by formula are not satisfactory for elevated stations. The errors introduced by the factor of temperature inversion are usually so great as to void any accuracy to be obtained by computation from the other factors. As a general rule it may be stated that the greater the influence of inversion on the minimum temperature at any station, the poorer will be the application of the minimum temperature formula. The formula must have at least as great a variation in application as the difference between the average and extremes of temperature departure due to inversion. Formula construction for an elevated city station is a hopeless task.

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The forecaster has many things to guide him. In general, it is easy to recognize the cases where the departrue will be in excess of 3° F. This occurs during serious freeze types of weather where the maximum temperature and dew point are unusually low, with an accompaniment of winds of decided force; or else when local winds and cloudiness are to be experienced during a portion of the night. The experience of the previous morning often is at hand. The amount of moisture in the surface soil sometimes offers a dependable means of correction. For the rest, the personal experience of the forecaster in his own particular district, and his personal ability to determine accurately the immediate weather from the current weather chart and translate these indications into the terms of degrees in temperature, is put to test.

The forecaster also must be able to differentiate between the conditions where frost will or will not occur. It is a fact that the majority of nights during the period when frost danger is most acute would be frosty if the sky remained clear and there was no surface wind. The hygrometric formula, being constructed from data taken on cold nights only, invariably indicates this tendency. But all nights during the frost season are not actually frosty. Some are cloudy; some are windy; and some are rainy. It is the forecaster's own job to segregate the nights when the formula will have application. Properly used, the formula will indicate about how low the temperature at the key station will fall under ideal frost conditions, and gives the forecaster a base upon which to build, but it has

nothing but theoretical application on nights when frost is not experienced. The hygrometric formula is not constructed for use on nights like these

Of the many temperature formulas that have been suggested, some are inherently faulty and others have but limited use. The family of temperature formulas based upon the hygrometric relationship has been shown in this paper to be outstandingly superior. It so happens, however, that within this family of hygrometric formulas there is one that maintains a flexibility in construction and accuracy in practical application in a degree not attained by the others. This is the Young formula wherein the basic relationship is linear and close construction given to the data by a series of arbitrary corrections.

Much in useful accuracy is lost if the variables V_d and V_h are not computed. It is not enough to carry the formula development only to the point where the base formulas are determined, for although in such cases there is likely to be excellent correlation between the factors, values usually can be assigned the variables which will result in even closer correlation. The variables provide:

1. For the influence of local topography, and,
2. An empiric evaluation of $f\ (L)$.

If only a short record is available for a key station where it is desired to develop a formula, it will be found that not enough data are at hand from which to construct a satisfactory formula of the Young type. In this case the Smith or Nichols type of formula is recommended, as these formulas lend themselves readily to interpolation. Later, a formula after Young's method can be constructed.

Any of the other formulas in the hygrometric family, when given the same treatment of arbitrary correction as used in Young's formula, have the same flexibility and accuracy. The smooth mathematical line of best fit is altered by the corrections to approach the position of an irregular line of best fit. There is no evidence to support the idea that the data on the dot chart must conform to some standard mathematical line or curve. The evidence, rather, points to the contrary view that, in most cases, the line of best fit is an irregular curve. By the application of the method of arbitrary corrections all the formulas in the hygrometric group are reduced to the same general irregular form regardless of the form of the base formula, whether parabola, hyperbola, free-hand curve, or straight line. In fact, all hygrometric formulas wherein the arbitrary corrections have been considered can be shown to be mathematically identical.

Selection of the Young straight-line formula as the superior formula of the hygrometric group is made for the reason that, since all the formulas when given similar treatment by arbitrary corrections are mathematically identical, it is proper to select the simplest means of accomplishing a desired end.

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UPPER-AIR CURRENTS AT HONOLULU, T. H.

By ANDREW THOMSON

[Apia Observatory]

A large amount of data regarding upper-air currents has been obtained at Honolulu, Territory of Hawaii, from the pilot-balloon observations taken for aviation purposes in its environs at the naval station, Pearl Harbor. Before January, 1924, few balloon flights were followed above 6 kilometers, so that studies of these data made by Blair (1) and Beal (2) were limited to winds of moderate altitude. It is the purpose of this article to discuss upper winds over Pearl Harbor (lat. 21° 22′ N., long. 157° 57′ W.), based on an analysis of 159 flights made between July, 1924, and July, 1927, all of which were followed above 5 kilometers and in one instance to 30 kilometers. These were evenly distributed over the three years and provide good material for the study of trade winds, although a larger number of flights was desired. I am indebted to J. F. Voorhees, meteorologist, United States Weather Bureau, Honolulu, for having placed them at my disposal. Although situated upon an island within the Tropics, Honolulu has both a very small annual rainfall (25.41 inches) and a large percentage of days with cloudless sky, which combine to make it an excellent location for aerological investigation.

Honolulu is situated southwest of the permanent high-pressure center of the eastern Pacific in an area where the NE. trades are prevalent throughout the whole year. From June to August winds from east to northeast blow for over 93 per cent of the time, and even in the winter season, when most interrupted by winds set up by cyclonic depressions, trades persist for 66 per cent of the time.

The percentage frequency of winds blowing from 16 points of the compass for half-kilometer levels up to 11 kilometers is given in Table 1.

TABLE 1.—*Frequency of winds from various directions at different altitudes above Pearl Harbor, Honolulu, 1924–1927*

Altitude (kilometers)	Number of observations	N.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW	NNW.
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Surface	141	15	5	18	35	11	1	3	1		1	2	1			1	6
0.25	154	3	1	23	44	13	3	2	1		2	1	2	3	2		1
.50	157		4	10	45	24	2	2			3	1	3	3	3		3
.75	155	1	1	6	44	26	4	3	1		1	2	3	2	3	1	1
1.0	159	3	1	8	30	26	10	3	1		2	1	3	3	4	1	3
1.5	157	4	6	7	16	27	10	4	4	1	2	2	3	3	4	4	4
2.0	154	2	6	11	17	17	12	8	5	1	3	4	3	4	2	3	2
2.5	156	3	5	11	14	17	15	4	5	1	4	6	3	3	2	3	4
3.0	153	7	5	12	11	10	14	9	5	1	2	5	5	5	3	2	4
3.5	155	6	7	13	12	8	12	6	3	1	3	6	8	3	3	3	6
4.0	158	8	4	8	11	10	4	7	4	3	4	4	10	6	6	7	5
4.5	158	2	8	6	8	8	5	8	6	2	6	6	10	6	6	4	8
5.0	154	5	4	7	10	6	6	4	5	1	6	10	9	6	5	9	7
5.5	151	4	7	5	9	5	7	3	2	3	8	10	7	8	9	5	8
6.0	131	5	4	8	8	5	5	2	5	2	8	5	5	15	9	7	8
6.5	90	9	4	7	10	1			2	1	7	6	9	12	10	9	13
7.0	74	12	7	7	11	1		3	1		4	6	12	7	12	10	8
7.5	68	7	7	6	12	2	2		3	2	2	4	16	3	12	16	7
8.0	63	6	5	6	13			3	2	3		5	13	11	14	11	8
8.5	53	6	4	11	4	4	2	4	2		2	6	6	15	17	17	2
9.0	41	5	2	7	5	5	2	2	5			7	2	20	10	17	10
9.5	35	3	3	9	9		6	3	3		3	3	11	17	9	14	9
10.0	27	4	7	7	11	4	4	4		7		4	15	7	11	11	4
10.5	27	11		15	11		4	4			4	4	7	11	11	11	7
11.0	24	8	4	17	4	8			4				8	13	8	13	13

The NE. winds at the surface veer with increasing altitude through E. and SE. to SW. and NW. until at 12 kilometers the winds have completed the circuit through 360°, and are blowing again from the NE. Only 9 balloons were followed above 12 kilometers and these would indicate northerly and easterly winds to 20 kilometers. In Figure 1 are given the directions of all flights above 11 kilometers which, although subject to considerable individual error through leaks in balloon fabric and vertical currents, give evidence of the existence of the upper NE. trade winds.

While the wind veers round as viewed from outside the earth in a clockwise direction it does not do so at a regular rate; there are two main currents continuing throughout the year, with intervening bands of winds with direction varying with the season. The two predominating wind currents are the NE. trades up to 2 kilometers and the NW. antitrades from 7 to 12 kilometers. Between these two main currents are southerly winds with direction depending upon the season. Above the NW. antitrade is the thin upper trade wind reaching to the tropopause. In the tropopause as Dobson has found in England the winds are subject to wide vagaries, both in direction and velocity. Above the trades, the great current of air is the NW. antitrade which, it is interesting to note, Ficker (3) has found playing an equally important rôle at Teneriffe in approximately the same latitude in the Atlantic Ocean.

In order to investigate the variation in the heights of winds with season, the observed wind velocity at each half kilometer was resolved into north-south and east-west components, the components being grouped in periods of two months. Although the results obtained at Honolulu by this method are believed to represent the state of affairs normally existent in nature, there are conditions not strikingly dissimilar when the method would lead to fallacious conclusions. Thus a belt of very strong winds blowing for nine-tenths of the time may sweep the balloons so far from the observer that they are lost in distance. The balloons released when light or contrary ground winds occur will continue to be observed through the belt of strong winds usually present into levels which are probably calmer than their normal state. There is a small selective effect in the 159 flights here discussed each of which is followed to at least 5 kilometers; the wind velocities up to 4 kilometers altitude are about 15 per cent less for each level than those given by Beals for 1,265 flights taken daily. The velocity components up to 10 kilometers are given in Tables 2 and 3.

TABLE 2.—*North-south wind components at Honolulu*

[The plus sign (+) indicates north component]

Altitude (kilometers)	Jan.-Feb., m. p. s.	Mar.-Apr., m. p. s.	May-June, m. p. s.	July-Aug., m. p. s.	Sept.-Oct., m. p. s.	Nov.-Dec., m. p. s.
0.25	+0.62	+1.18	+1.21	+2.25	+2.12	+1.17
0.50	0.00	+1.14	+1.00	+2.33	+2.04	+0.23
0.75	0.00	+0.74	+0.75	+1.78	+1.92	+0.09
1.0	−0.59	+0.69	+0.75	+1.80	+1.79	−0.41
1.5	−1.19	−0.09	+0.29	+0.75	+1.37	+0.20
2.0	−2.39	−0.66	−0.57	+0.64	+1.07	−0.29
2.5	−2.30	+0.31	−0.89	+1.06	+1.06	−1.46
3.0	−1.87	+0.19	−1.43	+1.05	+1.81	−0.22
3.5	−2.47	+1.05	−1.32	+0.66	+2.53	−0.18
4.0	−2.17	+1.69	−1.57	−0.20	+2.44	−0.73
4.5	−1.46	+1.73	−1.28	−0.64	+2.47	−0.27
5.0	−1.35	+1.22	−1.03	−0.87	+2.34	−0.21
5.5	−0.21	+1.45	−1.86	−1.59	+2.64	+0.39
6.0	−0.08	+3.28	−1.74	−1.25	+3.94	+0.39
6.5	+1.61	+2.21	−1.07	−2.28	+4.89	+1.68
7.0	+2.53	+2.30	−1.00	−3.08	+4.02	+2.16
7.5	+4.56	+4.88	−1.24	−4.18	+4.54	+2.58
8.0	+8.37	+2.92	−0.73	−3.59	+4.83	+1.93
8.5	+7.77	+3.18	+0.08	−2.27	+5.33	+1.98
9.0	+9.97	+7.62	−0.95	−6.07	+3.99	+4.30
9.5	+8.00	+5.13	−4.63	−5.95	+4.99	+6.21
10.0	+3.50	+4.33	+0.20	−5.47	+5.46	+4.68

TABLE 3.—*East-west wind components of velocity at Honolulu*

[The plus sign (+) indicates west wind]

Altitude (kilometers)	Jan.-Feb., m. p. s.	Mar.-Apr., m. p. s.	May-June, m. p. s.	July-Aug., m. p. s.	Sept.-Oct., m. p. s.	Nov.-Dec., m. p. s.
0.25	−2.56	−2.02	−2.08	−5.32	−3.41	−2.43
0.50	−3.87	−2.45	−2.60	−5.79	−4.05	−2.73
0.75	−4.17	−2.53	−2.37	−6.28	−4.84	−2.53
1.0	−3.76	−1.61	−2.15	−6.66	−4.67	−2.01
1.5	−2.60	−1.86	−1.87	−5.03	−3.01	−1.51
2.0	−2.50	−1.56	−2.15	−3.89	−2.36	−1.38
2.5	−2.65	−1.03	−1.93	−2.96	−2.30	−2.64
3.0	−1.46	+0.09	−1.18	−2.33	−2.12	−2.67
3.5	−0.61	+1.06	−1.23	−1.89	−1.68	−1.74
4.0	−0.10	+2.44	−1.00	−0.81	−0.55	−1.56
4.5	+0.27	+2.64	−1.04	−0.99	−0.16	0.00
5.0	+1.80	+3.99	−1.77	−0.26	+0.74	−0.02
5.5	+3.58	+5.29	−1.05	+0.62	+1.44	+1.30
6.0	+2.04	+5.68	−0.33	+2.75	+2.44	+0.75
6.5	+3.07	+7.95	+0.49	+3.98	+2.42	+1.03
7.0	+4.82	+5.36	+0.50	+3.32	+2.49	+0.77
7.5	+5.48	+4.20	−0.40	+5.50	+2.28	+2.08
8.0	+6.38	+8.78	−2.94	+5.84	+1.20	+4.11
8.5	+13.0	+9.88	−4.70	+7.14	+2.54	+3.51
9.0	+12.9	+10.22	−5.22	+6.57	+7.48	+2.20
9.5	+10.94	+5.73	−8.79	+8.63	+7.27	+2.84
10.0	+10.15	+6.33	+8.70	+8.25	+3.23	+1.96

Although the north-south components at the surface are strongest during May to September, it is to be noted that above 1 kilometer the absolute velocities are greater during January to April. The steeper temperature gradients set up during the winter months between the temperate zone and the equator produce a more vigorous circulation at the higher levels. The variation of the heights at which winds blow is most clearly seen from Figures 2 and 3, derived from the above tables.

(1) The NE. trade winds are shallowest from November to February when they have a depth of 1 kilometer and deepest from July to October when they are 4 kilometers thick. The upper NW. wind is weakest and thinnest during the northern summer from May to August. SE. winds would appear to interrupt the NW. current during May and June but there are few observations available to establish this result. There is a much greater development of winds from the south during summer which may be due to increased convection or to the dumping of air into the Northern Hemisphere by the SE. trades which are much stronger during these months. The United States Pilot Charts give their usual northern limit as 5° N. during June to August and 5° S. during December to February. Neither of these forces acts directly. The overflow from the south would have been deflected by the earth's rotation from this direction long before it reached Honolulu unless guided by other forces. The effect of the increased vertical currents in setting up stronger trades when the sun is overhead in June does not have its counterpart in the southern Pacific, where the trade winds are weakest during December and January, the months in which the sun's altitude is greatest.

From the velocity components the relative displacement of air east or west, and towards the Equator or the Pole was obtained for each kilometer stratum by multi-

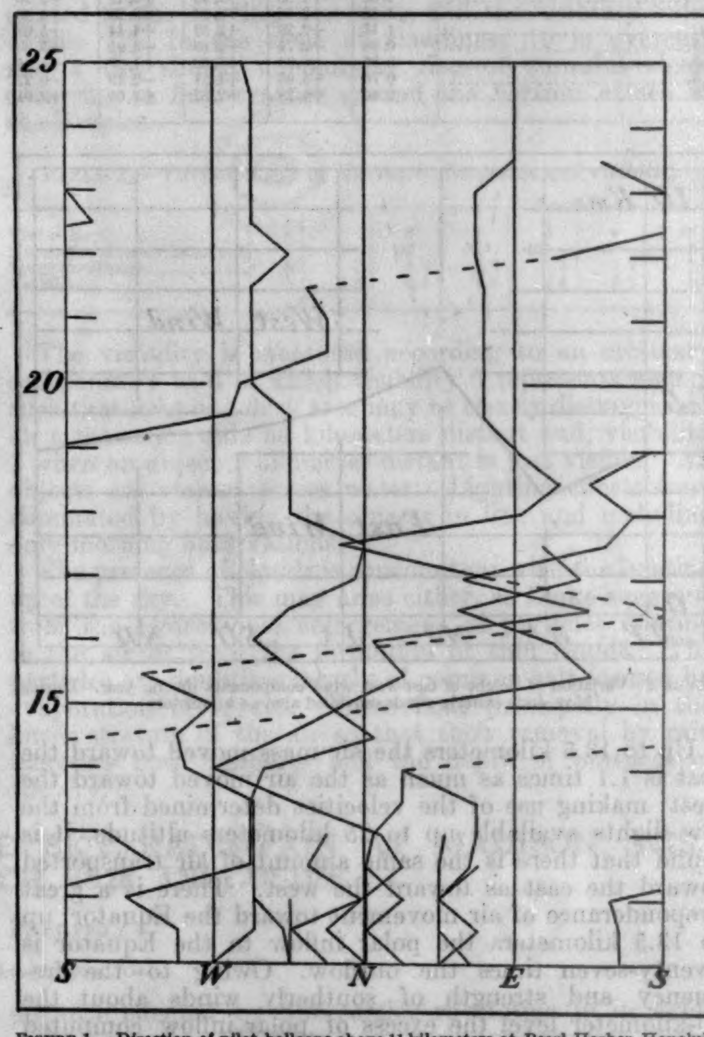

FIGURE 1.—Direction of pilot balloons above 11 kilometers at Pearl Harbor, Honolulu. Although showing wide variations there is evidence of northerly winds up to 20 kilometers

plying the velocity of each stratum by its density. The adopted mean velocity for layers up to 9 kilometers was obtained by taking the mean of the two monthly velocities, above 9 kilometers, owing to the uneven distribution of data the mean of all flights was used. Lacking density data based on observations at Honolulu, an air density midway between that found for Equator and for Canada was used. Since the air has the same density at these places at an altitude of 11 kilometers and has a maximum difference at 1 kilometer of only 5 per cent the error introduced by assuming a density midway between them must be slight. The relative displacement of air is given in Table 4.

TABLE 4.—*Relative displacement of air in layers 1 kilometer thick to an altitude of 14 kilometers*

[Air displacement =10×wind velocity in m/s×density of the air. Plus sign indicates north or east wind]

Height, kilometers	Density, g/m	North velocity component, m. p. s.	North displacement	West velocity component, m. p. s.	West displacement
0.5	3.32	+1.12	+3.98	−3.58	−11.88
1.5	3.00	+0.22	+0.66	−2.65	−7.95
2.5	2.70	−0.37	−1.00	−2.25	−6.08
3.5	2.42	+0.04	+0.10	−1.02	−2.47
4.5	2.19	−0.09	−0.20	+0.12	+0.26
5.5	1.98	+0.14	+0.28	+1.86	+3.68
6.5	1.78	+1.17	+2.08	+3.16	+5.62
7.5	1.60	+1.86	+2.98	+3.19	+5.10
8.5	1.36	+2.68	+3.64	+3.28	+4.46
9.5	1.13	+2.29	+2.50	+4.44	+5.02
10.5	0.98	+2.71	+2.66	+3.91	+3.83
11.5	0.86	+6.84	+5.88	+1.67	+1.44
12.5	0.76	+5.93	+4.51	−0.35	−0.27
13.5	0.66	+4.28	+2.82	+3.06	+2.01

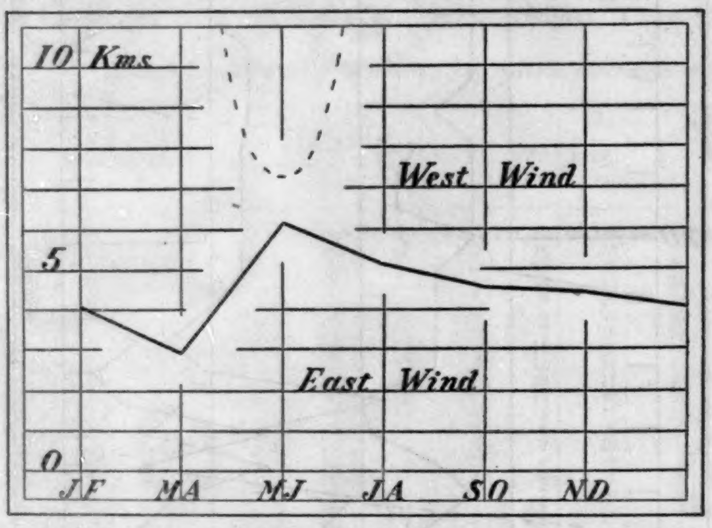

FIGURE 2.—Variation of height of east-west wind components during year. During May–June easterly winds prevailed above 6 kilometers

Up to 13.5 kilometers the air mass moved toward the east is 1.1 times as much as the air moved toward the west; making use of the velocities determined from the few flights available up to 25 kilometers altitude, it is found that there is the same amount of air transported toward the east as toward the west. There is a great preponderance of air movement toward the Equator; up to 13.5 kilometers the polar inflow to the Equator is twenty-seven times the outflow. Owing to the frequency and strength of southerly winds about the 20-kilometer level the excess of polar inflow computed from all flights up to 25 kilometers is reduced to 9.5 times the outflow from the Equator. Above the 25-kilometer level the density becomes so small that, even should southerly winds with exteremely high velocities occur at these heights, the total air mass moved toward the Equator would remain much greater than that moved poleward.

The trade winds have, until recently, been explained as the return flow at surface levels of the warm air which, having risen at the Equator to great altitudes, flows off toward the Pole; the rotation of earth deflecting the returning winds so that their approach to the Equator has an angle of 45° therewith. This simple explanation has been attacked by modern meteorologists, notably Sir Napier Shaw. To the modern view the intertropical circulation may be considered as currents of air flowing in between centers of high pressure guided along their course toward the Equator by pressure distribution and then after joining the equatorial current finding their way to high latitudes either at great altitudes or on the appropriate side of high-pressure centers. The old view would require above every point in the intertropical area an equivalence of air moving north and south. The Honolulu data show clearly that there is at that point not an equal north and south flow but a great mass of air being carried in toward the Equator. Above the Hawaiian Islands there is a continuous equatorward current of polar air; where this current works back to high latitudes is not clear.

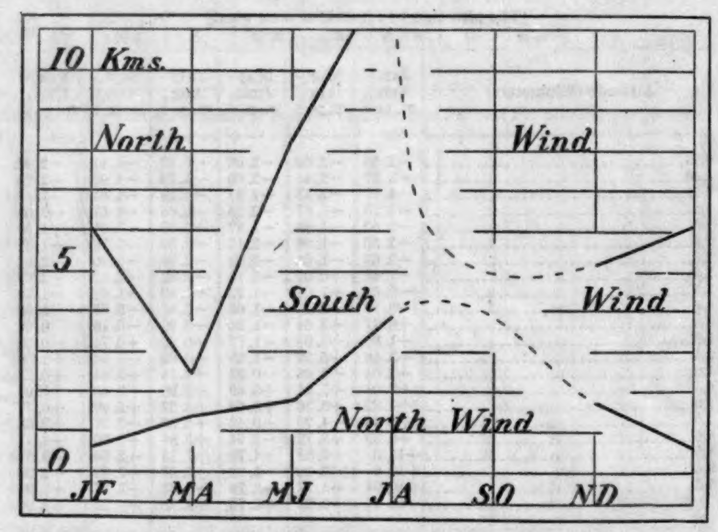

FIGURE 3.—Variation in height of north-south wind components during year. In September–October northerly winds occurred at all heights up to 11 kilometers

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BLUE-SKY MEASUREMENTS AT APIA, SAMOA

By ANDREW THOMSON

[Apia Observatory]

Observations on the blueness of the sky have been regularly made at Apia, Samoa (13° 48′ S., 171° 48′ W.), South Pacific Ocean from January, 1927, to October, 1928. The intensity or depth of the blue was determined on a scale devised by F. Linke by a method recently described in this journal.[1] The deepest blue, ultramarine, is designated tint 12; the lightest, a bluish white tint, is 2. The data are of interest on account of being taken at sea level on an island where contamination of the air by smoke or fog does not occur. The island, which is covered with dense vegetation, has an area of 450 square miles. Apia lies not far from the center of the south-east trade wind belt in extreme oceanic surroundings, the total land area within 1,500 miles being less than 1 per cent.

The color of sky was observed, when possible, at 9 a. m. and 3:15 p. m. In 19 months the sky has been found to vary from lightest tint 4, occurring once, to deepest tint 10, occurring eleven times. Table 1 shows the annual variation in blueness of the sky.

TABLE 1.—*Annual variation in blueness of sky at Apia, Samoa*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A. m.	7.0	7.4	7.3	7.0	7.6	6.8	8.0	7.8	7.8	7.9	7.5	7.3
P. m.	6.5	7.6	7.0	6.4	6.0	6.6	6.2	7.0	7.9	6.8	7.2	7.3

It is seen immediately that the sky is a deeper blue in the morning than in the afternoon, especially so during the trade-wind, or dry season, from May to September.

Dividing up the year into three seasons—wet, November to February; dry, May to August; and equinoctial, September, October, March, and April, the differences forenoon and afternoon are as follows:

	Mean	A. m.-p. m.
Dry	7.32	0.50
Equinoctial	7.11	.28
Wet	7.22	.15

[1] Linke, F. Mo. Wea. Review, June, 1928, **56**: 224.

There is obviously only a very slight seasonal change. The smallness of the a. m.-p. m value in the wet season is due to the frequency of the rain which produces constant humidity conditions throughout the day. In the dry season, the convection and vertical currents set up causes, both by the presence of slightly condensed water vapor and by the enlargement of salt particles, a whitening of the sky.

The blueness of the sky at any moment is closely related to the existing cloudiness and the visibility vide. (Table 2.) In the scale of cloudiness 10 is overcast and 1 the almost unchanging ring of cumulus cloud occurring in fine weather around the horizon at sea in the Tropics.

TABLE 2.—*Variation of sky blue with cloudiness and visibility*

Tint of blue	4	5	6	7	8	9	10
Number of observations	1	13	50	84	125	58	6
Mean cloudiness	6	5.7	5.0	3.9	2.3	1.9	1.8
Visibility	5	4.1	4.1	3.7	3.4	3.2	3.3

The visibility is measured according to an arbitrary scale from 1 to 6 in which visibility 6 represents seeing, such that light and dark area may be clearly distinguished on a mountain side 50 kilometers distant and, visibility 1 when an object 1 kilometer distant is just visible. All objects are viewed across water. Lighting effects were eliminated by having the objects in line and including only morning observations.

The presence of clouds is concomitant with the lighting up of the sky. This may arise either, as Linke suggests, from the hydroscopic enlargement of particles floating in the air or from the formation of thin clouds. The particles are doubtless largely of common salt formed by evaporation of sprays. These float principally in the lower stratum of the air so that their removal by rain increases both visibility and the depth of blueness of the sky.

SEVENTEEN-YEAR RECORD OF SUN AND SKY RADIATION AT MADISON, WIS., APRIL, 1911, TO MARCH, 1928, INCLUSIVE

By ARTHUR F. PIIPPO

[Weather Bureau Office, Madison, Wis.]

Introduction.—Beginning with April, 1911, a continuous record of the intensity of sun and sky radiation has been obtained at Madison, Wis., through the medium of the Callendar bolometric sunshine recorder. The record has been made by receiver No. 9864. For a description of the instruments, their errors, reduction factor, and exposure, the reader is referred to Kimball & Miller (1).

Radiation.—Summaries of the hourly, daily, weekly, and annual intensities and extremes have been tabulated and are presented here. Curves of normal and maximum intensities, etc., have been prepared from the data. The intensity of solar rays incident at a point on the earth's surface is chiefly dependent on the elevation of the sun with respect to that point. The incoming rays are absorbed in proportion to the thickness of the atmosphere; i. e., the air mass, m, through which they must pass. The regular fluctuations of daily and annual radiation are the result of the revolution of the earth on its axis, and the change in the sun's declination and distance effected by the earth's revolution in its orbit around the sun. The irregular variations are due to the effect of the weather and the change in the quality of the transmitting atmosphere.

Transparency.—The transparency of clear air is dependent upon three factors—the depletion of radiation due to the molecular scattering and absorption by dry air; by wet haze, or water vapor; and by dry haze, or dust. The last two vary greatly from a maximum in the warm season to a minimum in winter, as shown by Table 1. Transparency is here represented by means of the atmospheric transmission coefficient, a, computed from the equation, $a^m = \frac{Q'}{Q_0}$, where m equals air mass, Q' the value of the radiation intensity corresponding to m, reduced to mean solar distance, and Q_0 the value of the solar constant, here assumed to be 1.94.

Curves of radiation.—Curve 1, Figure 1, the maximum noon intensity of solar radiation on a normal surface as recorded by the Marvin pyrheliometer, although affected by the seasonal change in the value of m at noon, and the annual variation in the earth's solar distance, which is a maximum in July, shows the effect of a hazy atmosphere in reducing the intensity during the warm season of the year. Under cloudless skies the daily averages of the total radiation received on a horizontal surface give curve 3, Figure 1, which can be considered the normal curve of sun and sky radiation at Madison under clear-sky conditions. The maximum difference between it and curve 2, which latter gives the maximum daily amounts of sun and sky radiation, occurs in July, the time of maximum haziness. The greatest irregularity in the average daily totals of sun and sky radiation, as shown in curve 4, is a result of changes in the cloud cover incident to storminess. There is a decided depression in spring and more or less irregularity in autumn. In the Monthly Weather Review for June, 1920, Miller (2) has shown the annual march of storminess to have a double maximum, the primary one in spring and a secondary in October. It is apparent from the time of occurrence of maximum storminess, that cloudiness is the principal disturbing influence on the regular annual march of sun and sky radiation. Comparison with Miller's curve of nine-year means (2) shows that curve 4 has smoothed out considerably with increase in the length of record.

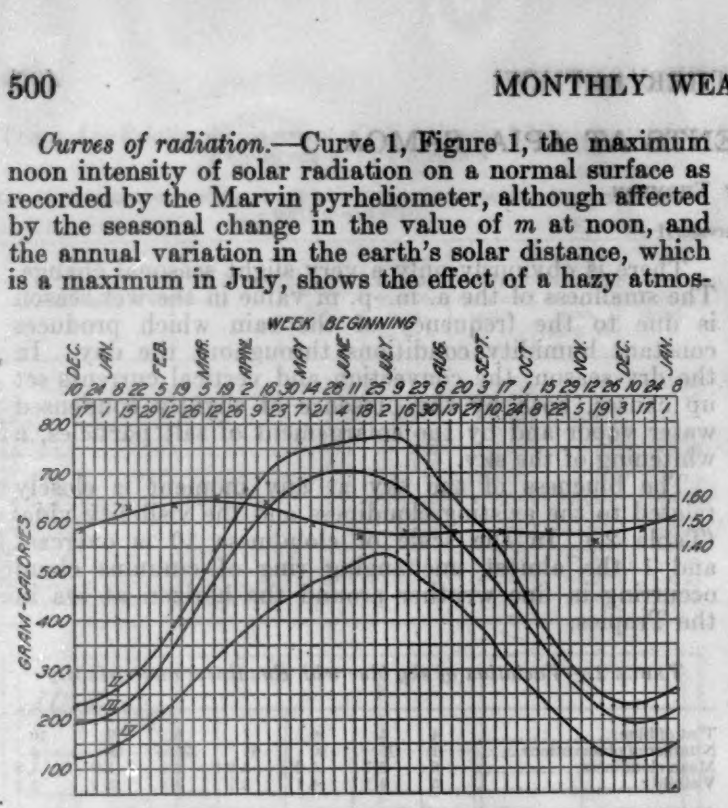

FIGURE 1.—Curve 1, maximum noon intensities of solar radiation on a normal surface as recorded by the Marvin pyrheliometer; 2, maximum daily amounts of sun and sky radiation on a horizontal surface; 3, mean daily amounts of sun and sky radiation on a horizontal surface under clear skies; 4, mean daily amounts of sun and sky radiation on a horizontal surface in calories per square centimeter

Radiation history.—Figure 2 is constructed from the data partially presented in Table 7. That table gives the monthly and annual sums of the sun and sky radiation. The departure of these values from the normal is represented by the smooth dotted curve in Figure 2 and this is the most interesting, yet it is somewhat baffling. Since the beginning of the record it shows a quite steady decrease. Mention here must be made of the fact that the record for the first 16 months, during which period a different recorder was in use, is not considered entirely reliable and probably is too high. Were that period to be disregarded entirely, the steady decline in radiation would still appear. The atmospheric transmission coefficients, a, have been calculated for the different periods and are given in Table 2. It has been suggested that the increase in the smokiness, due to increased population in the city and to the replacing of hard coal by bituminous fuels, has decreased the transparency. Examination of the data in Table 2 fails to reveal anything to verify this assumption. The mean transparency for the winter months, for example, is very nearly 85 per cent for the four periods given. Location of the observing station north and west of the greatest smoke-producing sections of the city should be taken into consideration, as the bulk of the observations with the Marvin pyrheliometer, from which the transparency is computed, occur on days when the station is on the windward side of these smoke-producing centers.

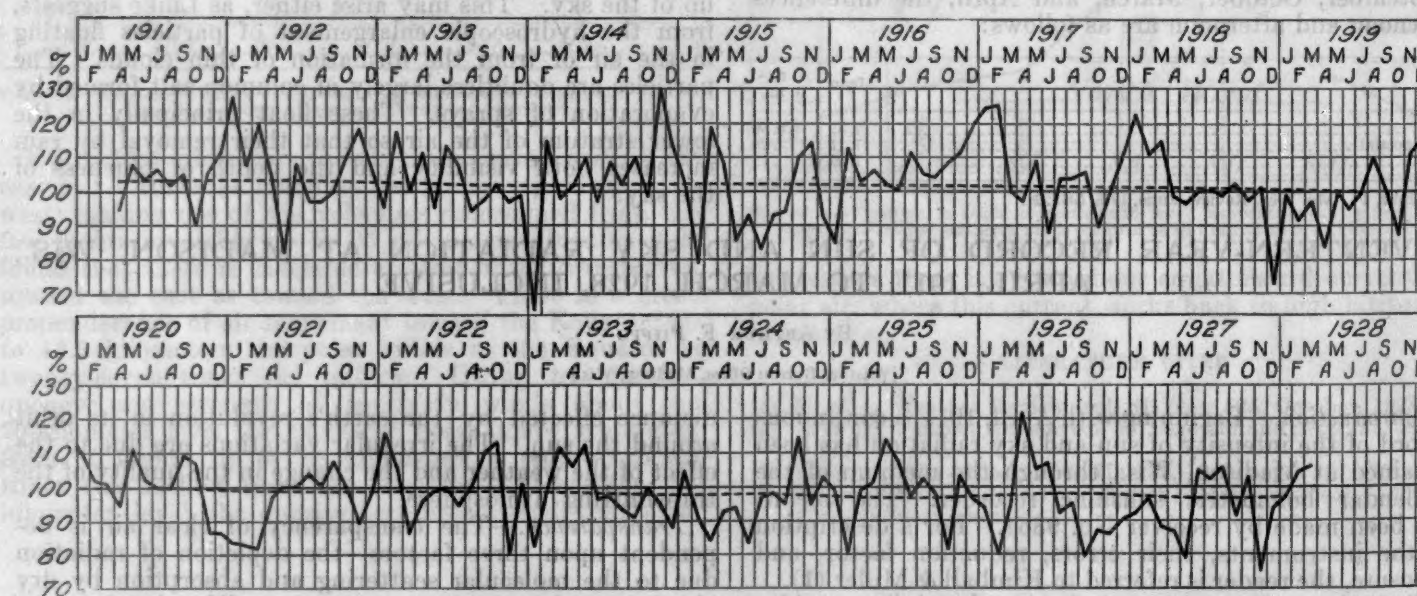

FIGURE 2.—History of sun and sky radiation at Madison, Wis., from April, 1911, to March, 1928, including monthy departures in percentages of the mean and annual departure, the smooth curve

That fact more or less vitiates as a basis for comparison, the transparency factor obtained from the Marvin instrument. The officials of one of the leading fuel companies in the city estimates the use of anthracite fuel to have decreased 60 per cent in the last 15 years, while the population has doubled in the same period. Users of hard coal have sutstituted coke, fuel oil, gas, and principally bituminous fuels, thereby adding materially to the hazi-

ness during the cold season. Table 3 offers little light on the problem. The mean cloudiness during daylight hours is presented in percentages and shows clearer skies, on the whole, during the latter half of the record. It can not, however, be reasonably presumed that the increased haziness due to increased smokiness can account for the entire decrease in radiation unless one concludes it from the fact that considerable deficiencies in radiation are shown by the majority of the winter seasons during the last 10 years. Another interesting feature of the graph is the long-continued deficiency extending from July, 1926, to May, 1927, inclusive, during which period the total loss was 12,591 calories, or more than the total of an average April. Winter months receiving low radiation totals have high temperature means as a rule, while those with high excesses of insolation are low in temperature value. The association of clear, cold weather with high radiation values, and the low radiation income with warm, cloudy weather is apparent.

Tables.—Table 4 gives the mean hourly and daily intensity of the vertical component of sun and sky radiation, from which curve 4, Figure 1, has been constructed. Table 5 gives the radiation values under clear sky conditions, and has been used to construct curve 3, Figure 1. Table 6 gives a summary of the means and extremes of radiation since the beginning of the record.

Acknowledgments.—The writer wishes to acknowledge his indebtedness to Doctor Kimball, of the central office, for the data from which Table 1 was computed, and to Mr. E. R. Miller, the official in charge of the Madison, Wis., station, for many helpful suggestions.

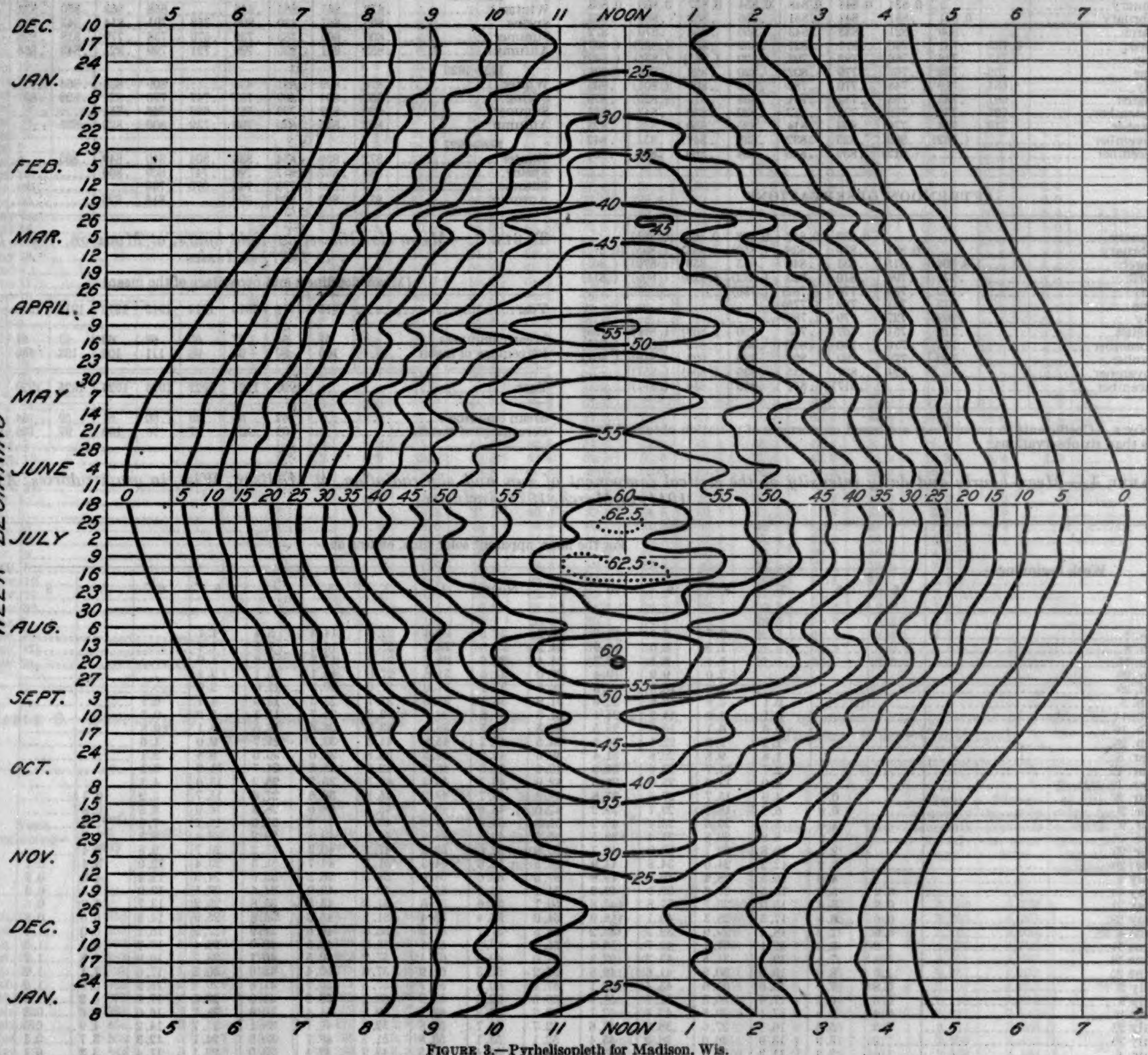

FIGURE 3.—Pyrhelisopleth for Madison, Wis.

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(1) KIMBALL, H. H., and MILLER, E. R.
1916. The total radiation received on a horizontal surface from the sun and sky at Madison, Wis., April, 1911, to March, 1916. Monthly Weather Review, 44: 180–181.

(2) MILLER, E. R.
1920. Measurements of solar radiation at Madison, Wis., with the Callendar pyrheliometer. Monthly Weather Review, 48: 338–343.

TABLE 1.—*Atmospheric transmission coefficient, a, for Madison, Wis., computed from 16½ years' record of observations of solar radiation, normal incidence, with the Marvin pyrheliometer*

MORNING OBSERVATIONS

Month	Air mass 1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
January			0.824	0.844	0.848	0.854	0.857	0.860	0.863
February		0.831	.831	.841	.851	.856	.862	.860	.863
March		.809	.821	.833	.843	.850	.854	.870	.872
April	0.737	.781	.796	.811	.827	.852	.857	(.862)	(.867)
May	.717	.746	.760	.785	.793	.820	(.841)	(.836)	(.849)
June	.702	.738	.766	.779	.802	.820	.828	.828	(.806)
July	.681	.719	.748	.770	.782	.795	.801	(.804)	.803
August	.691	.733	.763	.782	.791	.808	.815	(.825)	.829
September	.721	.758	.779	.794	.812	.822	.830	.843	.855
October	.712	.754	.779	.803	.814	.825	.830	.823	.823
November		(.762)	.809	.825	.832	.838	.847	.851	.849
December			(.812)	.839	.845	.854	.860	.863	.863

AFTERNOON OBSERVATIONS

Month	Air mass 1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
January				0.839	0.843	0.858	0.865	(0.881)	
February			0.831	.839	.838	(.850)	(.865)	(.895)	(0.877)
March		0.804	.815	.831	.840	.865	.859	(.872)	(.861)
April		.777	.796	.810	.823	(.832)	(.820)	(.809)	(.811)
May		.750	.739	.770	(.782)	(.786)			
June		.733	.751	.782	(.775)				
July		.709	.727	.779	(.782)				
August		.719	.751	.767	.765	.790	(.808)	(.817)	(.798)
September		.754	.776	.790	.807	.803	.815	(.817)	(.857)
October		.760	.779	.799	.804	.820	.823	(.819)	(.801)
November			.824	.827	.835	.836	(.854)	(.851)	
December				(.817)	.859	.850	.854	(.877)	

NOTE.—Coefficients in parentheses are based on normals of radiation obtained from less than six observations.

TABLE 2.—*Means of the atmospheric transmission coefficient, a, at Madison, Wis.*

	A. M. Air mass 5.0	4.0	3.0	2.0	1.0	P. M. 2.0	3.0	4.0	5.0	Mean
1911–1915										
Winter	0.852	0.882	0.856	0.831		0.836	0.859	0.845		0.852
Spring	.865	.857	.837	.789	0.686	.776	.854	.862		.816
Summer		.815	.771	.742	.649	.696	.728	.775	0.756	.742
Autumn	.820	.826	.807	.776	.696	.751	.809	.799	.774	.784
1916–1920										
Winter	.872	.867	.865	.846		.858	.868	.850	.873	.862
Spring	.865	.857	.830	.806	.758	.791	.814	.843	.815	.820
Summer	.806	.806	.783	.739	.670	.736	.779	.818	.826	.774
Autumn	.853	.841	.830	.790	.721	.790	.821	.843	.866	.819
1921–1925										
Winter	.873	.862	.851	.833		.809	.838	.865		.847
Spring	.852	.834	.809	.789	.747	.770	.821	.828	.837	.810
Summer	.820	.823	.799	.753	.686	.746	.751			.768
Autumn	.852	.845	.830	.799	.732	.806	.823	.835		.815
1926–1927										
Winter	.872	.859	.854	.836	.804	.840	.849	.865		.847
Spring	.889	.857	.817	.796	.747	.809	.856			.824
Summer		.826	.793	.748	.676	.736				.756
Autumn	.877	.850	.830	.806		.815	.823			.834

TABLE 3.—*Mean cloudiness, daylight hours, at Madison, Wis., 1911 to 1927, inclusive*

[Mean cloudiness and percentage of the mean]

Year	1911	1912	1913	1914	1915	1916	1917	1918	1919
Mean cloudiness	61	54	57	60	68	62	63	61	67
Percentage of mean	100	89	93	98	111	102	103	100	110

Year	1920	1921	1922	1923	1924	1925	1926	1927
Mean cloudiness	62	65	59	60	61	59	64	60
Percentage of mean	102	107	97	98	100	97	105	98

TABLE 4.—*Mean hourly and daily intensity of the vertical component of sun and sky radiation, at Madison, Wis., in gram calories, April, 1911, to March, 1928, inclusive*

Week beginning—	For the hour, apparent solar time, ending at— 5	6	7	8	9	10	11	Noon	1	2	3	4	5	6	7	8	Daily
Jan. 1				0.7	6.1	13.6	20.2	24.5	24.4	21.0	14.4	6.4	1.1				132.3
Jan. 8				1.2	8.0	16.9	24.2	27.6	28.4	23.7	16.3	7.5	1.4				155.2
Jan. 15				1.4	8.1	16.7	24.4	28.6	28.6	24.3	17.3	8.6	1.9				160.0
Jan. 22				2.0	9.9	19.4	27.0	31.6	31.8	27.0	19.1	10.1	2.4				180.3
Jan. 29				2.6	10.3	19.3	26.8	31.1	31.0	27.0	20.3	11.0	2.9				182.2
Feb. 5			0.1	3.8	12.6	22.9	31.9	36.1	35.6	31.7	23.5	13.6	4.1	0.1			216.0
Feb. 12			0.1	4.9	14.5	24.1	31.8	36.8	36.7	32.3	24.7	15.1	5.2	0.3			226.2
Feb. 19			0.5	6.1	15.9	25.5	32.5	36.5	36.9	33.3	26.6	16.5	6.1	0.8			237.2
Feb. 26			1.2	9.2	22.1	34.5	43.5	47.2	45.8	41.3	33.3	21.7	9.0	1.6			310.4
Mar. 5			1.8	9.8	20.8	31.4	39.6	42.2	41.5	36.8	30.0	20.0	9.4	2.1			285.2
Mar. 12			2.7	11.7	23.6	34.9	42.6	46.3	46.5	42.9	35.5	24.7	11.9	3.1			326.4
Mar. 19			4.0	13.9	25.9	36.0	42.9	46.7	46.3	42.5	35.7	25.2	13.6	4.1			337.0
Mar. 26		0.1	4.9	15.7	27.5	37.8	44.8	48.7	49.2	45.6	38.6	27.6	15.7	5.2	0.3		362.0
Apr. 2		0.6	6.7	18.3	29.7	39.2	47.0	48.6	49.1	45.4	38.0	28.8	16.9	6.3	0.8		375.4
Apr. 9		1.0	8.5	20.6	33.4	45.2	51.8	54.9	54.3	49.8	41.8	31.0	19.2	7.8	1.3		420.5
Apr. 16		1.5	8.8	20.3	31.4	39.5	46.3	49.3	48.9	46.6	40.8	29.2	18.4	8.3	1.7		391.0
Apr. 23		2.3	10.8	22.1	33.9	43.7	50.8	52.6	52.2	47.1	40.3	31.2	20.7	9.8	2.4		420.1
Apr. 30		3.2	12.2	24.0	34.8	44.9	52.5	55.6	54.3	51.1	44.7	35.3	23.4	12.0	3.4	0.1	451.5
May 7		4.6	15.5	28.4	40.3	49.8	57.5	59.6	58.0	54.3	46.5	35.9	24.5	12.4	4.0	0.2	491.5
May 14	0.2	5.0	15.5	27.6	38.6	49.2	54.1	56.5	55.5	50.7	42.0	34.4	23.5	12.9	4.4	0.3	470.2
May 21	0.3	5.4	15.0	26.7	37.8	45.8	50.7	54.6	53.6	51.3	43.8	35.8	25.2	13.7	4.9	0.6	465.0
May 28	0.6	6.8	17.3	28.3	40.1	48.9	54.0	56.4	56.4	51.1	45.3	36.6	25.9	14.8	5.5	0.8	488.5
June 4	0.9	7.2	18.4	29.9	39.7	48.2	54.5	57.1	57.9	55.8	49.0	39.9	27.9	16.2	6.0	1.2	510.0
June 11	1.0	8.0	19.1	31.1	42.7	50.9	55.7	58.3	58.1	53.3	48.5	40.0	28.4	16.3	6.3	1.2	518.7
June 18	1.1	7.8	19.1	31.5	43.2	52.3	57.0	60.3	61.1	57.2	50.5	40.7	28.7	16.9	6.8	1.2	535.5
June 25	1.0	8.0	19.6	30.8	41.6	49.8	57.2	62.3	61.9	57.6	50.4	42.0	30.3	17.6	7.1	1.2	538.5
July 2	0.8	7.0	18.6	31.6	43.4	52.1	57.1	60.4	59.7	57.5	50.7	41.6	29.4	15.9	5.9	1.0	532.5
July 9	0.6	6.2	17.9	30.6	42.7	51.9	60.0	62.8	60.8	60.2	52.2	41.9	29.5	17.0	6.2	1.0	541.4
July 16	0.4	5.8	17.1	29.8	42.4	52.7	59.2	63.2	63.1	59.1	51.4	40.8	28.7	16.0	5.6	0.8	536.1
July 23	0.3	5.3	16.1	27.6	38.9	47.6	52.7	55.7	55.8	52.8	46.1	38.1	25.7	14.2	4.9	0.5	482.2
July 30		3.9	13.9	26.0	36.0	45.4	52.1	55.1	56.8	51.7	43.7	35.6	24.1	12.3	3.7	0.1	460.2
Aug. 6		2.8	11.3	22.9	33.5	42.2	49.1	50.4	50.5	48.9	42.4	33.0	22.1	11.4	3.3	0.1	423.8
Aug. 13		2.3	10.8	23.3	35.2	45.6	54.0	58.3	56.9	54.0	45.4	34.7	22.9	10.3	2.7		456.5
Aug. 20		1.5	9.6	22.3	34.7	45.0	54.1	59.3	58.2	52.5	47.0	36.6	23.6	10.1	2.1		456.8
Aug. 27		1.0	8.9	21.1	33.7	43.4	51.2	56.5	56.6	52.1	43.9	33.0	19.9	8.0	1.4		431.0
Sept. 3		0.6	6.6	17.3	29.0	39.0	45.7	48.1	46.9	42.0	36.3	26.5	14.9	5.4	0.7		359.2
Sept. 10		0.3	4.7	15.0	25.3	35.0	42.1	45.7	43.2	40.2	33.2	23.9	14.1	4.3	0.4		327.5
Sept. 17		0.1	4.2	14.6	26.6	37.2	43.8	47.1	45.6	41.1	34.8	24.2	12.6	3.4	0.1		335.4
Sept. 24			2.9	12.2	23.7	33.1	39.1	42.3	41.7	37.0	30.3	20.7	10.2	2.4			295.6
Oct. 1			1.8	9.5	20.4	30.3	37.6	40.8	40.7	36.8	30.1	19.5	8.5	1.8			278.0
Oct. 8			1.0	7.0	17.2	26.8	34.2	37.7	37.2	33.4	26.6	17.5	6.7	1.1			246.3
Oct. 15			0.5	5.9	15.7	24.5	31.2	34.3	33.8	29.9	23.5	14.4	5.2	0.7			219.8
Oct. 22			0.2	4.8	13.9	23.1	29.8	33.0	32.1	27.9	22.0	13.1	4.3	0.2			204.4
Oct. 29				3.6	12.6	21.8	29.8	33.2	32.0	28.0	21.7	12.3	3.6				198.8
Nov. 5				2.4	9.2	17.5	24.2	27.9	28.2	24.0	17.4	9.9	2.4				163.1
Nov. 12				1.5	7.6	15.5	21.5	24.7	24.4	20.8	14.5	7.7	2.0				140.3
Nov. 19				1.2	6.5	13.3	18.7	22.4	22.8	19.5	13.7	6.7	1.5				126.0
Nov. 26				0.8	5.8	12.3	17.6	20.2	20.2	16.7	12.1	5.6	1.1				112.2
Dec. 3				0.7	5.9	12.8	18.1	21.0	20.8	17.4	12.2	5.6	1.1				115.6
Dec. 10				0.6	5.8	13.9	19.9	23.1	22.8	19.2	13.1	5.8	1.0				126.0
Dec. 17				0.5	5.4	12.4	18.4	21.2	21.1	18.5	12.3	5.5	0.9				115.9
Dec. 24				0.6	5.9	13.7	19.7	23.8	23.3	19.2	13.2	6.1	1.1				126.4

33751—29——2

TABLE 5.—*Average hourly and daily intensity of the vertical component of sun and sky radiation at Madison, Wis., under cloudless skies, in gram calories*

Week beginning—	For the hour, apparent solar time, ending at—																Daily
	5	6	7	8	9	10	11	Noon	1	2	3	4	5	6	7	8	
Jan. 1				1.3	10.4	22.6	32.3	38.0	38.2	31.6	21.6	8.7	1.5				206.2
Jan. 8				1.7	11.1	24.1	34.5	40.1	40.5	33.4	23.3	10.5	2.0				221.2
Jan. 15				2.1	12.6	25.3	35.4	41.8	41.0	34.2	23.6	11.4	2.2				229.6
Jan. 22				3.2	14.5	27.6	37.0	42.8	42.7	36.1	25.1	12.4	2.7				244.1
Jan. 29				3.8	15.6	30.0	40.9	46.7	47.2	41.0	30.6	16.2	4.0				276.0
Feb. 5				4.6	19.1	33.2	44.6	50.7	50.1	44.8	33.9	18.5	5.4				304.9
Feb. 12			1.2	6.9	22.1	38.0	49.3	55.3	53.9	47.4	36.6	22.1	6.6	1.0			340.4
Feb. 19			1.4	10.7	26.6	41.2	52.5	58.5	57.6	50.4	40.7	25.3	8.7	1.4			375.0
Feb. 26			1.3	10.9	28.7	44.6	56.6	62.2	61.5	55.2	45.3	29.4	11.2	2.2			409.0
Mar. 5			2.5	15.0	33.7	49.1	60.6	66.0	64.8	58.4	48.1	33.0	14.5	2.8			448.5
Mar. 12			3.9	18.3	36.4	51.7	62.8	67.7	67.0	60.8	50.2	34.9	16.6	4.0			474.3
Mar. 19			5.7	21.7	40.2	55.2	66.2	70.8	69.5	63.1	53.7	38.6	20.4	5.6			510.7
Mar. 26		1.0	7.4	24.7	43.4	58.3	69.3	74.4	73.4	67.1	55.9	40.8	22.1	6.5	1.2		545.5
Apr. 2		1.1	9.9	28.7	47.2	61.7	71.8	76.4	75.8	70.3	60.3	44.9	26.1	9.2	1.3		584.7
Apr. 9		1.4	12.3	31.4	50.3	64.3	74.2	78.9	78.0	72.0	61.1	46.7	28.0	11.4	1.9		611.9
Apr. 16		2.5	14.9	32.7	50.5	63.6	72.8	78.1	77.8	71.9	62.0	46.7	30.2	12.7	2.3		618.7
Apr. 23		3.5	17.9	36.5	53.7	67.8	77.4	81.4	80.3	75.0	65.8	51.0	33.5	14.3	3.4		661.5
Apr. 30		4.5	19.1	37.4	54.1	67.0	75.3	79.4	78.5	72.6	63.7	49.8	33.0	15.9	4.0		654.3
May 7		5.6	20.9	38.7	55.2	68.1	77.5	82.0	81.7	76.5	66.8	53.6	36.8	18.6	5.4	1.2	688.2
May 14	1.0	7.1	23.5	40.8	56.6	68.8	76.6	80.1	78.7	74.6	65.2	52.3	35.8	18.8	6.0	1.1	687.0
May 21	1.5	8.4	24.5	41.7	57.3	68.7	76.7	80.2	80.4	76.4	66.8	55.0	37.0	20.9	7.0	1.5	704.0
May 28	1.1	8.7	24.4	40.3	54.9	66.0	74.2	78.9	78.5	73.3	65.6	51.5	35.9	21.6	8.2	1.8	684.9
June 4	1.1	10.0	26.6	42.7	56.8	68.1	76.0	79.7	79.0	74.7	66.5	54.7	38.7	22.2	8.0	1.7	706.5
June 11	1.3	9.7	27.2	43.7	58.5	68.9	76.2	81.1	79.7	74.3	66.7	53.2	38.1	22.4	8.5	1.7	711.2
June 18	1.5	11.1	27.4	43.7	57.7	68.5	76.8	79.7	78.8	73.5	65.0	53.7	38.0	22.3	8.5	1.7	707.9
June 25	1.4	10.3	26.6	43.0	57.0	67.1	75.0	79.4	79.7	74.7	66.9	54.3	38.3	21.8	7.9	1.7	705.1
July 2	1.2	8.7	24.2	40.4	54.6	65.0	72.6	77.0	77.0	72.2	64.4	51.6	36.6	21.3	7.4	1.5	675.7
July 9	1.1	8.0	23.1	39.2	53.5	65.4	72.8	77.7	76.1	71.2	64.0	52.5	37.2	20.9	7.4	1.4	671.5
July 16	1.0	7.5	23.2	39.6	54.1	64.9	73.2	76.6	75.9	70.5	62.8	49.9	34.9	19.0	6.0	1.5	660.6
July 23	1.0	6.3	21.1	37.5	52.2	64.0	71.5	75.7	76.4	71.7	63.4	48.7	32.8	17.6	5.5	1.1	646.5
July 30		5.0	19.3	35.8	50.3	61.8	70.1	74.6	74.0	68.7	60.2	48.0	32.8	17.2	5.1	1.0	623.9
Aug. 6		4.1	17.6	34.3	49.3	60.6	69.4	72.2	71.9	67.6	59.7	46.8	31.9	15.1	4.2		604.7
Aug. 13		3.0	15.0	31.2	46.7	59.2	67.8	72.2	72.0	66.8	56.7	44.2	28.5	12.6	3.1		579.0
Aug. 20		1.9	12.8	29.4	45.3	57.8	67.2	70.6	69.0	64.5	56.8	43.5	27.0	11.0	2.2		559.0
Aug. 27		1.4	11.1	27.5	43.8	56.5	65.6	69.0	68.1	62.9	52.1	38.9	23.3	3.7	1.5		530.4
Sept. 3		1.2	9.2	25.4	41.0	52.8	61.0	64.9	63.8	58.3	49.4	37.5	19.3	6.1	1.3		401.2
Sept. 10		1.2	6.9	23.3	40.5	53.4	62.5	65.6	65.3	59.6	49.3	35.3	19.3	5.4	1.2		488.8
Sept. 17			4.9	19.5	35.8	49.8	59.0	63.0	62.0	56.7	47.2	33.3	16.5	3.9	1.0		452.6
Sept. 24			3.9	17.9	34.7	49.0	58.2	61.5	60.5	55.2	45.4	31.3	14.8	2.9			434.8
Oct. 1			2.4	13.3	29.2	42.3	52.3	56.5	55.7	50.2	40.3	26.9	11.2	2.2			382.5
Oct. 8			1.7	10.8	27.2	40.3	50.3	54.5	52.7	47.3	37.9	24.6	8.8	1.6			357.7
Oct. 15			1.0	8.0	23.4	36.9	46.7	51.9	51.1	45.8	35.6	21.7	7.1	1.3			330.5
Oct. 22			1.0	6.5	21.0	34.2	44.1	48.5	47.3	41.0	31.3	18.2	5.5	1.1			299.7
Oct. 29				4.6	18.0	30.9	41.3	46.1	45.4	39.4	29.9	16.4	4.2				276.2
Nov. 5				3.8	15.2	28.3	38.4	43.6	42.3	36.5	27.2	14.3	3.3				252.9
Nov. 12				2.6	13.1	26.6	36.7	42.7	42.7	36.9	27.1	13.7	3.1				245.2
Nov. 19				2.0	10.6	22.6	32.1	37.8	37.1	31.0	21.5	10.1	2.1				206.9
Nov. 26				1.4	9.6	21.0	31.2	36.2	35.7	30.5	20.4	8.7	1.7				196.4
Dec. 3				1.2	9.1	20.4	30.1	34.8	34.6	28.5	19.0	8.3	1.6				187.6
Dec. 10				1.2	9.1	20.6	29.6	34.7	34.8	29.3	19.8	8.4	1.7				189.2
Dec. 17				1.4	10.7	22.3	31.5	35.8	34.7	28.8	19.3	8.3	1.6				194.4
Dec. 24				1.3	9.7	21.1	30.6	36.2	35.2	28.8	19.4	8.6	1.5				192.4

TABLE 6.—*Summary of means and extremes of radiation, etc., at Madison, Wis.*

Week beginning—	Greatest daily	Month	Day	Year	Mean monthly amounts for all days	Mean monthly amounts for clear days	Duration of sunshine, for months. (Percentage of possible)	Mean cloudiness, daylight hours, for months
Jan. 1	252	1	1	1912	926	1,443		
Jan. 8	259	1	9	1912	1,086	1,548		
Jan. 15	289	1	19	1912	1,120	1,607	45	63
Jan. 22	282	1	23	1915	1,262	1,709		
Jan. 29	323	1	31	1918	1,275	1,932		
Feb. 5	363	2	9	1912	1,512	2,134		
Feb. 12	371	2	18	1923	1,583	2,383	47	65
Feb. 19	394	2	20	1917	1,660	2,625		
Feb. 26	455	2	29	1912	2,173	2,863		
Mar. 5	503	3	7	1920	1,996	3,140		
Mar. 12	544	3	16	1923	2,285	3,320	52	63
Mar. 19	552	3	22	1916	2,359	3,575		
Mar. 26	609	3	29	1912	2,534	3,819		
Apr. 2	666	4	7	1911	2,628	4,093		
Apr. 9	692	4	14	1911	2,944	4,283		
Apr. 16	682	4	17	1916	2,737	4,330	53	65
Apr. 23	734	4	24	1911	2,941	4,631		
Apr. 30	743	5	3	1911	3,161	4,580		
May 7	762	5	11	1916	3,441	4,817		
May 14	739	5	16	1927	3,291	4,809	59	62
May 21	751	5	27	1922	3,255	4,928		
May 28	755	5	30	1915	3,420	4,794		
June 4	765	6	9	1913	3,570	4,946		
June 11	769	6	16	1917	3,630	4,978	64	60
June 18	765	6	19	1916	3,749	4,955		
June 25	770	6	28	1911	3,770	4,936		

TABLE 6.—*Summary of means and extremes of radiation, etc., at Madison, Wis.*—Continued

Week beginning—	Greatest daily	Month	Day	Year	Mean monthly amounts for all days	Mean monthly amounts for clear days	Duration of sunshine, for months. (Percentage of possible)	Mean cloudiness, daylight hours, for months
July 2	764	7	2	1917	3,728	4,720		
July 9	789	7	12	1911	3,790	4,701		
July 16	788	7	21	1911	3,753	4,624	69	51
July 23	754	7	24	1913	3,375	4,526		
July 30	711	8	1	1913	3,221	4,367		
Aug. 6	661	8	6	1921	2,967	4,232		
Aug. 13	658	8	14	1921	3,196	4,053	64	52
Aug. 20	610	8	24	1923	3,198	3,913		
Aug. 27	649	8	29	1911	3,017	3,713		
Sept. 3	572	9	5	1921	2,514	3,438		
Sept. 10	554	9	11	1917	2,293	3,422	55	57
Sept. 17	559	9	19	1911	2,348	3,168		
Sept. 24	480	9	25	1921	2,069	3,044		
Oct. 1	456	10	2	1913	1,946	2,678		
Oct. 8	390	10	11	1914	1,726	2,504		
Oct. 15	364	10	15	1913	1,539	2,314	51	58
Oct. 22	327	10	27	1914	1,431	2,098		
Oct. 29	334	11	2	1911	1,392	1,933		
Nov. 5	275	11	8	1914	1,142	1,770		
Nov. 12	283	11	14	1916	982	1,716	37	69
Nov. 19	232	11	22	1914	882	1,448		
Nov. 26	228	11	29	1911	785	1,375		
Dec. 3	230	12	3	1911	809	1,313		
Dec. 10	225	12	15	1919	862	1,324	36	68
Dec. 17	232	12	18	1921	811	1,361		
Dec. 24	225	12	30	1914	885	1,347		

TABLE 7.—*Monthly and annual sums of the 17-year mean of the sun and sky radiation upon a horizontal surface at Madison, Wis., from April, 1911, to March, 1928, inclusive, in gram calories per square centimeter*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Year
1911				11,742	15,843	16,153	17,202	14,072	10,598	6,533	4,554	4,217	100,644
1912	6,297	6,953	12,006	12,663	11,948	16,891	15,623	13,380	10,001	7,932	5,137	4,024	122,855
1913	4,651	7,584	10,008	13,380	13,906	17,704	17,413	13,028	9,829	7,380	4,218	3,717	122,818
1914	3,196	7,422	9,854	12,213	16,238	15,203	17,417	14,128	11,060	7,070	5,656	4,320	123,767
1915	4,988	5,062	11,883	13,069	12,494	14,605	13,273	12,884	9,429	7,934	4,947	3,519	114,087
1916	4,117	7,292	10,272	12,727	15,024	15,673	17,872	14,516	10,486	7,793	4,831	4,469	125,072
1917	6,106	8,147	10,031	11,730	16,002	13,630	16,736	14,239	10,562	6,400	4,319	4,190	122,092
1918	5,982	7,145	11,446	11,883	14,194	15,681	16,187	13,711	10,246	7,026	4,395	2,697	120,593
1919	4,878	5,926	9,739	10,042	14,752	14,779	16,014	15,297	9,970	6,298	4,820	4,342	116,857
1920	5,357	6,616	10,175	11,432	16,410	16,007	16,219	13,783	10,940	7,701	3,712	3,266	121,618
1921	4,130	5,394	8,219	11,649	14,794	15,671	16,842	13,837	10,889	7,317	3,864	3,680	116,286
1922	5,710	6,937	8,677	11,437	14,380	15,664	15,112	14,032	11,039	8,177	3,481	3,788	118,434
1923	4,025	6,502	11,122	12,712	16,529	14,986	15,655	12,928	9,069	7,218	4,149	3,302	118,197
1924	5,166	6,015	8,465	11,085	13,810	12,952	15,579	13,530	9,591	8,417	4,128	3,868	112,606
1925	4,869	5,161	9,916	12,167	16,795	16,920	15,596	14,050	9,810	5,823	4,478	3,649	119,234
1926	4,638	5,185	9,530	14,732	15,497	16,722	14,760	13,120	7,940	6,262	3,708	3,392	115,486
1927	4,532	6,286	8,816	10,515	11,592	16,362	16,489	14,601	9,131	7,444	3,282	3,502	112,552
1928	4,749	6,743	10,635										
Means	4,906	6,492	10,047	12,053	14,718	15,623	16,117	13,832	10,035	7,219	4,334	3,761	119,137

DISCUSSION

Note on Figure 2 of Piippo's paper.—The author intimates in his text that the rather steady decrease in the annual totals of radiation, as indicated by the broken line in Figure 2, can be accounted for in part only by increased smokiness of the atmosphere of Madison due to an increase in the consumption of bituminous coal as a fuel in recent years. Also, while there is, in general, accord between average annual cloudiness and the total annual radiation from year to year, there is no evidence of an increase in cloudiness in recent years as compared with the earlier years covered by the pyrheliometric record.

It remains to ascertain if the recording pyrheliometer may not have deteriorated during the 17 years it has been in use. There are three ways in which we might expect deterioration, as follows:—

(1) The blackened grids might become less black or the platinum wires of the bright grid might tarnish. Visual observations do not indicate that this is the case.

(2) The glass dome covering the grids might become less transparent. Visual observations do not show that this is the case. However, such observations are quite inconclusive.

(3) A sliding contact on a bridge wire maintains a balance in the two arms of the bridge which is a part of the register, and if this wire becomes worn its resistance increases and less movement is necessary to balance the heating of the black grids by radiation of a given intensity. In consequence there is lessened movement of the pen over the intensity scale of the record sheet. Since the wire has been kept coated with oil there can have been little wear on the wire.

Nevertheless, there is opportunity for deterioration of the apparatus in the manner indicated above, and the only practicable way to detect it is to recalibrate the pyrheliometer occasionally.

In Table 8 are given summaries of comparisons between the measurements of the intensity of the vertical component of direct sunshine by the Callendar and the Marvin pyrheliometers.

The ratios shown indicate that the Callendar register now records 3 per cent lower than it did in the years 1913–1915, and this will account for about half the decrease in annual radiation receipt during the above period. The remaining half I am inclined to attribute to increased smokiness, which is not apparent in the atmospheric transmission coefficients of Table 2 for the reason that observations with the Marvin pyrheliometer are not made on days when the atmosphere contains much smoke.

TABLE 8.—*Values (f) of a scale division of the Callendar pyrheliometer in gram calories per minute per square centimeter, as determined by comparisons between the Callendar and Marvin pyrheliometers*

Years	Solar altitude	Number of observations	f	Solar altitude	Number of observations	f	Solar altitude	Number of observations	f
1913–1915	58.3	15	0.0346	43.0	16	0.0342	29.8	14	0.0354
1917	60.6	10	.0353	43.6	7	.0354	30.2	5	.0377
1927				41.2	19	.0358	30.9	14	.0367
Ratio $\frac{1917}{1913\text{–}1915}$			1.020			1.035			1.065
Ratio $\frac{1927}{1913\text{–}1915}$						1.047			1.037
1913–1915	20.1	3	.0380	15.9	3	.0423	14.3	3	.0502
1917	21.8	4	.0371						
1927	22.5	8	.0382	15.6	2	.0417	12.6	1	.0489
Ratio $\frac{1917}{1913\text{–}1915}$			.0976						
Ratio $\frac{1927}{1913\text{–}1915}$			1.005			.0986			.0974

Weighted mean ratio (all Solar altitudes) $\frac{1917}{1913\text{–}1915}$, 1.024 $\frac{1927}{1913\text{–}1915}$, 1.032.

The Marvin pyrheliometer at Madison was compared with Smithsonian pyrheliometer No. 1 on September 29, 1928, and the mean of three series, each covering a period of about 30 minutes, gave for the ratio $\frac{\text{Marvin}}{\text{Smithsonian}}$ the value 1.002. Smithsonian No. 1 is frequently compared with substandards at the Smithsonian Institution. It was last compared on February 28, 1928, and was found to be in accord with them within the error of observation. This has been the result of all comparisons made since May 3, 1920; and since July 12, 1910, the change in the ratio between Smithsonian substandards and Smithsonian No. 1 has been only 0.7 ± 4.34 per cent, No. 1 appearing to read that amount lower at the present time.—*H. H Kimball.*

COMMERCIAL AIRWAYS WEATHER SERVICE—PRESENT STATUS AND FUTURE PROSPECTS

By WILLIS RAY GREGG

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(Presented at the meeting of the American Meteorological Society in New York City, December 27, 1928)

INTRODUCTION

As two and a half years have elapsed since the passage of the air commerce act, it is perhaps timely to review what has been done in that period to make air commerce safe and efficient, and to follow this up with a brief outline of what is proposed for the future.

It was my privilege to talk on this subject at the society's meeting in Philadelphia in December, 1926. Then we had barely started; the service was still in the formative stage. Nevertheless the general character of that service had been determined and a policy for its development had been outlined and adopted. Let us recall briefly the principal features of the service as then set forth. They are:

1. Frequent reports showing current conditions, both surface and upper air.
2. Short-range forecasts giving the outlook for from one to five or six hours, the length of this period depending upon the scheduled duration of any given flight.
3. General weather forecasts for the next 12 to 24 hours.

It is interesting to note that these still remain the dominant features of the service, and that their relative importance is now, as then, that of the order in which they are listed above. Experience has shown, however, that the service must be much more intensive than at first thought, in order that it may contribute its proper share toward safety and efficiency. The organization in the past two years has therefore been in the direction of expansion to cover new airways and intensification along all airways.

THE AIRWAYS AT THE CLOSE OF 1926

At the close of 1926 the transcontinental airway was the only one on which flights were being made both day and night. Not all of it was lighted, but a sufficient part was, to make possible the transportation of mail from one end to the other without stops other than for unloading, loading, and refueling. This was the trunk line of the system. From this there were extensions or branches, for daytime flying only, from New York to Boston; Chicago to St. Louis, Dallas, and the Twin Cities; Cheyenne to Pueblo; Salt Lake City to Pasco and Los Angeles; and San Francisco to Los Angeles and Seattle.

THE AIRWAYS AT THE CLOSE OF 1928

A map (fig. 1) recently issued by the aeronautics branch of the Department of Commerce is illuminating as an index of the expansion that has taken place in the past two years. In the West there is one principal addition, that of the airway between Salt Lake City and Great Falls, and in the Middle West the Chicago-Dallas airway has extensions to Galveston and Laredo, the latter connecting with a Mexican airway to Mexico City.

But it is in the Lake region and in the Eastern States that the largest extension has occurred. There is an intricate network in and south of the Great Lakes region. Atlanta has now become an important center, with through service to Chicago, New York, New Orleans, and Miami. From Miami a line goes to Habana, and shortly this will be extended to the Canal Zone and to Porto Rico. New York has an outlet to the North through an airway that now ends at Montreal and that ties in at Albany with regular service to Syracuse, Buffalo, and Cleveland, where it again joins the trunk line; something like 14,000 miles in all, with about half the distance equipped for night flying, and the plan now is to light some 3,000 miles more during the next year.

In addition there is quite definite talk of two more transcontinental airways—one along the northern and the other along the southern border, with, of course, numerous interconnecting lines, not to mention several offshoots into Canada, Mexico, the West Indies, and eventually to more distant transoceanic countries. As rapidly as possible these are to be lighted and provided with suitable intermediate landing fields, radio, and other aids.

WHAT OF THE WEATHER?

One of the chief aids is weather service. What has been done about it? And what is being planned for the future?

1. *Present status*.—Since 1926, when the air commerce act was passed, service in greater or less detail, depending upon the amount of air traffic, has been organized along all of the commercial airways that have been established or recognized as such by the Department of Commerce. This new service is of course an extension of that already existing for the general public, which consists of twice-daily reports from all parts of the country and forecasts based thereon, these forecasts covering periods of 12 to 36 hours.

Although that service was very early found to be of a too general character to suit the needs of fliers, it did provide the groundwork or parent organization, and as such was capable of expansion at comparatively little additional cost. One of the first acts in making this expansion was to increase the number of what we may call "upper air" stations; that is, those at which observations are made of winds at flying levels. In all, there are now some 50 such stations, well distributed over the country, many of them being located at important points on the airways themselves.

Information regarding upper wind directions and velocities, although helpful in enabling the pilot to select the most favorable flying level, is not vital in the same degree as is similar information concerning conditions at the surface. It is this latter information that determines whether or not any flight at all can be made. Fog, low-lying clouds, excessive rain, sleet or snow, severe thunderstorms, and very poor visibility render flying hazardous and at times impracticable. Not always will this be so, but in the present state of the art it is. Therefore, particular attention is given to these conditions, not only at the upper air stations but also at numerous places where observations are confined to surface weather. In all, there are now approximately 150 stations, most of them on the airways, from which such reports are available when needed. The accompanying map (fig. 2) shows

the distribution of these stations. It will be noted that in addition to the first-order stations, nearly all of which are at important airports, there are numerous secondary or substations, these being placed at fairly frequent intervals. Many of these are at intermediate landing fields. All are selected with reference to the topographic or meteorological conditions which make reports from them valuable and in many cases necessary. For example, such stations are established in regions where fogs are frequent. In one case, two stations are less than 10 miles apart, one being on a high ridge and the other in the lowland. Oftentimes, during bad weather, a landing can be made in one while the other is fogged in. Therefore, reports from both are essential. The reports from these secondary stations are based upon observations made by properly instructed though not technically trained personnel and with a set of instruments for indicating only the more important elements. They are accurate, but not of the high precision required in the general or primary system covering the entire country at 8 a. m. and 8 p. m.

Before each flight a pilot wants answers to the following questions:

(a) What is the weather now at the terminal?
(b) What is the weather now along the route?
(c) Will there be any change during the flight, and if so, what kind of a change?

Answers to these questions require a fast and dependable system of communications and trained meteorologists at the receiving centers. Communications may be called the backbone of the service. It is not for the meteorologist to say what system is best, but he is sure of one thing, namely, that whatever system is adopted it must be under absolute control. The solution appears to be the joint employment of two or more different systems. Just now much attention is being given to the typewriter-printer, or "teletype," for ground communication. Very likely other and perhaps better means will be devised in the future. Final selection will depend upon which system is most prompt, most dependable, and smoothest in operation.

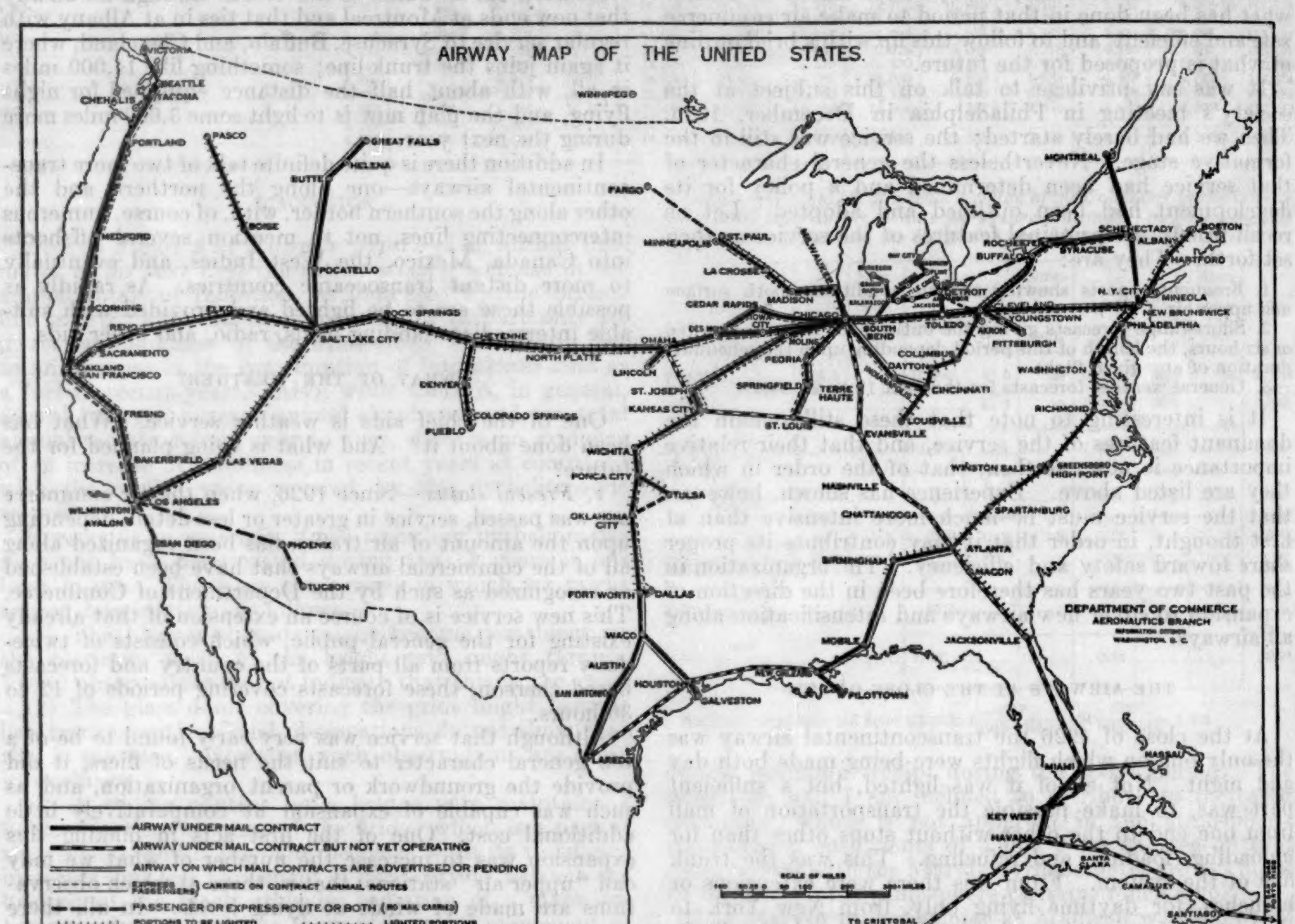


FIGURE 1.—Commercial airways in operation at the close of 1928

The other requirement, that of close contact with the pilot, is one that the meteorologist must himself provide. The telephone, or any other "distant control" arrangement, will not answer in this case. Experience is conclusive on this point, to the extent in fact that assignment of competent personnel at the more important airports is now the established policy of the Weather Bureau. Here he can see and study the reports "hot off the wire," make his forecasts, and talk the situation over with the pilot.

The reports themselves contain information regarding the general character of the weather, as clear, overcast, rain, snow, etc.; ceiling or height of low clouds; visibility;

wind direction and velocity; temperature and pressure; and when available, upper wind data. They are used by the meteorologist not only in giving out information concerning current conditions, but also as a basis for short-range airways forecasts for the following one to five or six hours. The utility of these short-range forecasts is becoming increasingly evident. It is no exaggeration to say that, in the early days of flying, pilots in general paid comparatively little attention to forecasts unless a very long flight was contemplated. For short trips current reports were deemed sufficient. Many experiences, however, some of them involving considerable hazard and a few of them resulting in accidents, have shown very clearly that a condition reported as existing at any given time may and often does change decidedly in the course of so short a period as an hour or so. Accordingly, on nearly all airways, the current reports are now supplemented by forecasts of probable changes in existing conditions, with particular reference to type of weather, ceiling, and visibility.

In addition to the current reports and short-range forecasts, the service to civil aeronautics provides forecasts covering periods of 12 to 24 or more hours. These are the general forecasts, augmented to include upper winds. They are of necessity couched in more general terms than are the short-period forecasts. In commercial aeronautics regular schedules must be maintained so far as possible. The operator wants to know to-day the likelihood of making a scheduled flight to-morrow. Particularly is this true in passenger-carrying service. If the probability is that no flight can be made or that there will be considerable delay, the prospective passenger can be so informed and can then, if he so desires, make his trip by train or bus. It seems likely that these longer-period forecasts will become more and more important as the service develops.

Such in brief is the present status of aeronautical meteorology in this country, so far as its practical application in providing current service is concerned. Hand in hand with this development progress is being made on the statistical side, resulting in the publication of data, including wind roses, for hundreds of airports, and landing fields. Meteorological surveys have been and are being conducted locally in and near certain cities with a view to determining the most favorable site for an airport. Just now, through cooperation with one of the air transport companies, recording instruments are being carried on air mail trips for the purpose of investigating the conditions favorable for the formation of ice on aircraft. It is hoped that this investigation will result in making possible more accurate forecasting of such conditions. There are other researches that are under consideration and still others that should be undertaken as rapidly as time and facilities permit.

2. *Future prospects.*—The development of civil flying has been so spectacular and on so large a scale that it is difficult to predict to what lengths it will ultimately proceed. But whatever those may be, certain it is that aids to make it safe and efficient must keep pace with it—must so far as possible be ready for it before the need arises.

During the year now closing two interesting and significant experimental weather and communication services have been inaugurated—one between San Francisco and

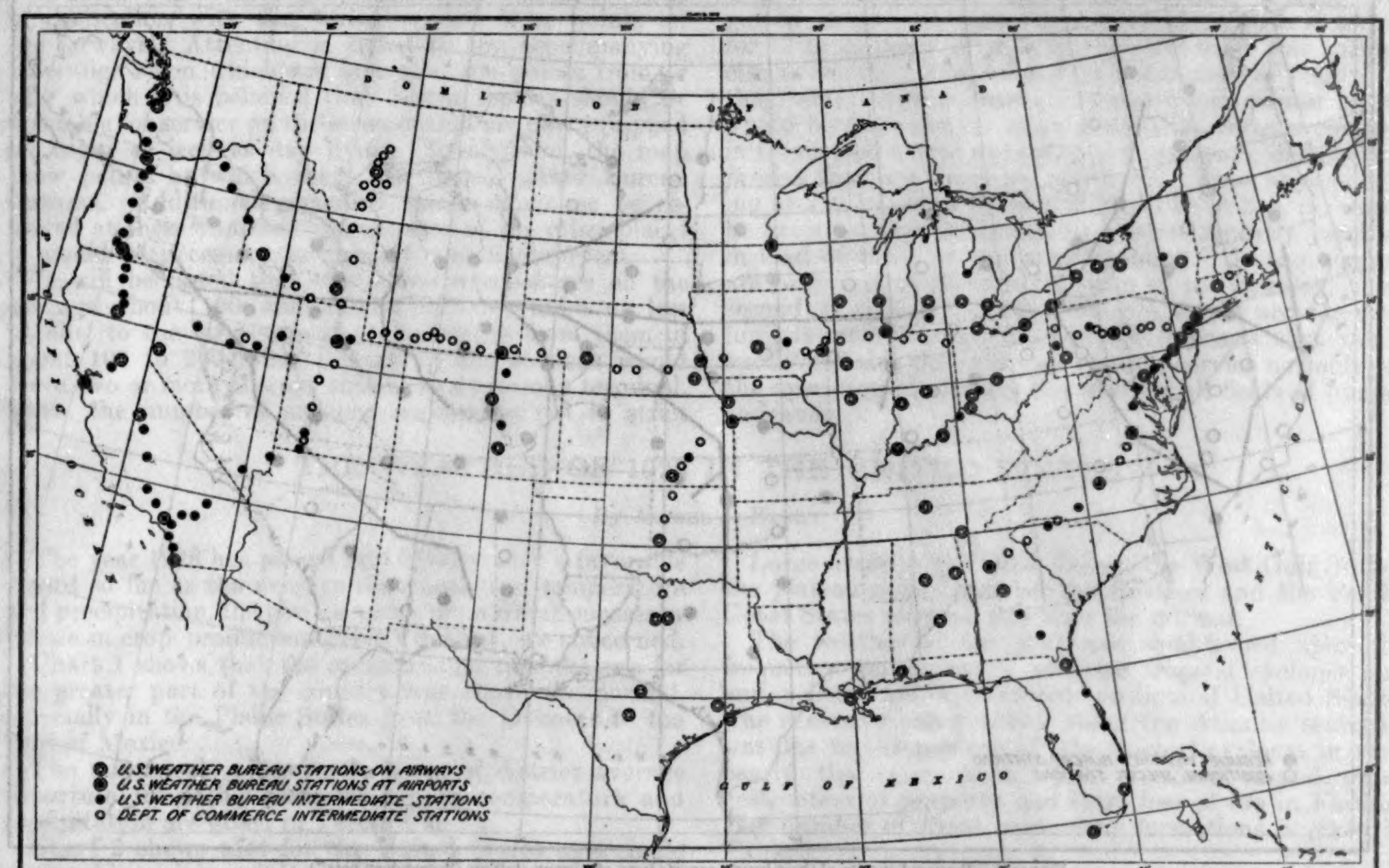


FIGURE 2.—Weather-reporting stations on commercial airways at the close of 1928

Los Angeles, organized by the Daniel Guggenheim Fund for the Promotion of Aeronautics and now operated by the Weather Bureau; the other between Hadley Airport and Cleveland, organized and operated by the Weather Bureau and the Department of Commerce. These two services have many features in common. Both have as their basis of requirement the experience of the past two years which has shown that frequent, regular reports from a close network of stations both on and off the airways are a necessity for safe, and particularly for efficient, operation of airways. From this experience, augmented by the lessons learned in the past few months from the experimental services, there has crystallized a plan of organization toward which it is proposed to work as rapidly as the needs require and facilities permit. The main features of this plan may be briefly outlined.

(*a*) As the fundamental feature there is of course the country-wide (extending beyond this country, in fact) twice-daily system of weather reports, on which are based the weather maps, bulletins, and general forecasts. It is hoped that, in the not distant future, the effectiveness of this system will be very greatly increased by having these reports made four times instead of twice daily as at present.

(*b*) Supplementary reports at 3-hour intervals from comparatively small areas or secondary nets, each area or net covering a section of an airway. These 3-hour reports would of course synchronize with those at 12 or 6 hour intervals. At present the airways service, with some exceptions, gives only occasional reports (timed to fit all scheduled flights) from points on the airways themselves. With the increase of air traffic it has been found that these intermittent reports do not meet the need satisfactorily, and that the absence of reports from points off the airways frequently results in unfavorable weather approaching them from one side or the other with no advance warning. The reports from the secondary nets at 3-hour intervals would enable the meteorologists at airports to follow the development and movement of disturbances approaching the airways from either side and to caution the pilots regarding them. The primary purpose of this 3-hour system of reports is thus seen to be to make possible the preparation and issuance of short-range airways forecasts.

(*c*) Still further supplementing the 12 or 6 hour reports there would be hourly reports of weather and landing conditions from numerous points on the airways themselves. These reports would be broadcast to planes in the air. Unfortunately there are and will always be, at least for a long time to come, many occasions when the weather outlook is decidedly uncertain even to the best trained meteorologist. This is where the value of a ground-to-plane communications system is shown. The pilot starts out perhaps with good weather prevailing and expected, but a fog suddenly develops at his terminal. A radio message tells him so and instructs him either to turn back or to land at some field nearest his terminal where conditions are still good.

(*d*) The need of a prompt and dependable system of communications for collecting the reports at important centers has already been stressed. Commercial telegraph will probably continue to furnish adequate service for the primary network, or the 12-hour reports and later the 6-hour reports. For the secondary nets of

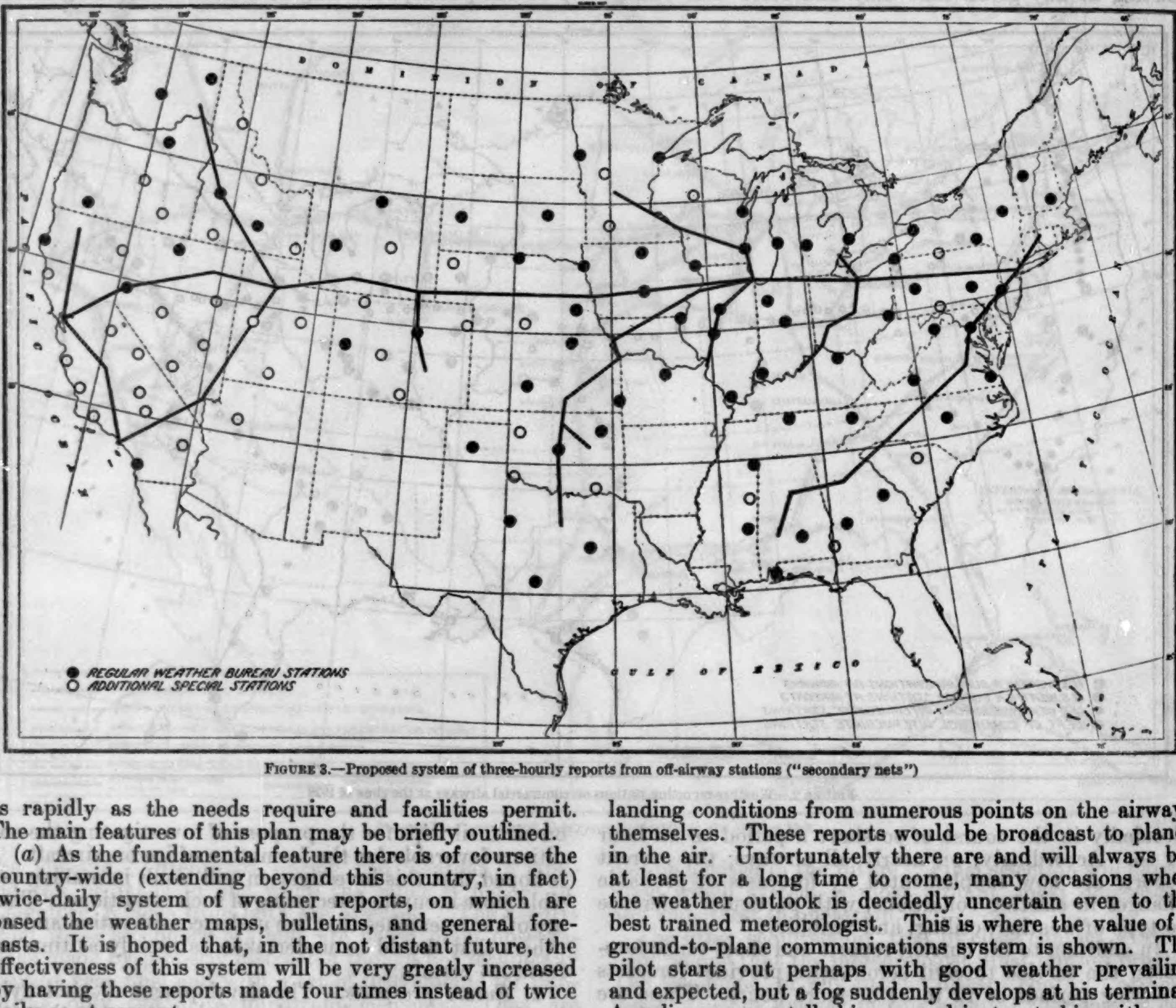


FIGURE 3.—Proposed system of three-hourly reports from off-airway stations ("secondary nets")

3-hour reports from small areas the telegraph will answer in many cases. In others it seems likely that the telephone will have to be used. But for the hourly reports from stations on the airways there must be a communications system that is not subject to use by outside parties; in other words, a leased wire, either telegraph, telephone, or teletype, with all intermediate reporting points tied in with the main or control stations.

Let us consider briefly what this proposed plan for meeting the needs of airways entails in the way of new service. There is already in existence the primary network of stations for the 12 or 6 hour reports. And, as earlier indicated, the airways themselves are quite well provided with intermediate stations for the hourly reports.

It appears that the principal expansion will be required in connection with the 3-hour reports from points off the airways. Attention is called to the accompanying map (fig. 3) on which are indicated the points from or near which it is believed that 3-hour reports should be available for service on the airways that are now equipped for night as well as day flying. Symbols on the map show points at which there are now Weather Bureau stations. Additional personnel would of course be required at these stations. In the case of the other places it would be necessary to appoint special observers.

It will be noted that the points selected are on the average about 100 miles apart in lines more or less parallel to the airways and at a distance from them of about 100 to 200 miles. Many of the stations would serve two or more airways that have a common terminal. Thus, the number of stations required is not in strict ratio to the total mileage. In the proposed set-up 116 stations would serve 7,700 miles of airways, although the average distance between the stations is approximately 100 miles.

The proposed extension will cost considerable money. But so does a passenger plane. So does the operation of a lighting system for night flying. So do airports. The prevention of the crash of one plane filled with passengers, or the increase in efficiency; that is, the increase in arrivals on schedule, by 2 or 3 per cent, would more than justify the cost, which after all would be but an infinitesimal fraction of the total amount involved in commercial aeronautics.

One of the important by-products of intensive service such as that proposed would be its application to all other lines of industrial and commercial activity. People have gotten along with forecasts expressed in general terms, for 12 to 36 hours in advance, because there was nothing else available. These must be continued, of course, as they serve many purposes. But of much greater utility would be forecasts for short periods in advance couched in terms that would naturally be much more definite and precise than are those we now have. Thus anyone asking at 1 p. m. what the weather will be at 3 p. m. would be given a forecast based on reports recently received instead of those in the early morning. As the airways are extended to include all parts of the country, these secondary nets of reporting stations would provide data for relatively precise, short-period forecasts that would vastly increase the utility of weather service not only for the operation of airways but also for all fields of human endeavor.

THE WEATHER OF 1928 IN THE UNITED STATES

By ALFRED J. HENRY

The year 1928 has passed into history with a favorable record so far as the average distribution of temperature and precipitation, the two elements upon which success or failure in crop production greatly depend, are concerned.

Chart 1 shows that the mean annual temperature for the greater part of the country was above the normal, especially in the Plains States from the Dakotas to the Gulf of Mexico.

The numerical values in the form of district average departure from the normal for both temperature and precipitation are given in Tables 1 and 2.

Chart 2 shows that for the United States as a single geographic unit precipitation was close to the normal, some districts, the East Gulf States, the Atlantic seaboard south of New England, the States of Kansas, Missouri, Iowa, Oklahoma, and parts of the surrounding area received greater than the normal rainfall. Large areas in the Ohio Valley, the West Gulf States, the plateau region west of the Rockies, and the Pacific Coast States received less than the normal.

The weather of the year was conditioned upon the frequency and intensity of extra tropical cyclones and anticyclones which traversed continental United States. The excessive precipitation along the Atlantic seaboard was due to the passage of two tropical cyclones in very nearly the same path. One of these caused great destruction of property and large loss of life in Florida. The number of these barometric formations is given in Table 3.

One hundred and sixty-one tornadoes, great and small, were reported during the year. The Rockford, Ill., tornado of September 14 caused a loss of life of 14 and the injury of 100 persons, this being the greatest casualties in any single storm.

TABLE 1.—*Monthly and annual temperature departures, 1928*

Districts	January	February	March	April	May	June	July	August	September	October	November	December	Average monthly departure
New England	+3.9	+0.9	+0.4	−1.2	−1.3	−1.9	+0.9	+2.9	−2.0	+1.5	+1.8	+5.3	+0.9
Middle Atlantic	+2.5	+1.6	+0.5	−1.8	−1.6	−1.8	+0.7	+2.2	−2.9	+1.9	+2.6	+3.1	+0.6
South Atlantic	0.0	+0.1	+0.8	−1.7	−2.3	−0.2	+0.5	+1.4	−1.2	+2.7	+0.4	+0.6	+0.2
Florida Peninsula	−2.9	+2.0	+1.3	+0.2	−1.8	−0.1	+0.6	+0.2	+0.2	+1.3	−0.7	−0.4	±0.0
East Gulf	−0.9	−1.2	+0.6	−3.4	−1.9	−1.3	+0.2	+1.5	−1.1	+3.2	−0.7	−0.2	−0.4
West Gulf	+1.7	+0.5	+1.7	−4.3	−0.1	−1.3	+0.3	+2.0	−1.6	+4.0	−0.9	−0.1	+0.2
Ohio Valley and Tennessee	+0.4	+0.5	−0.9	−3.6	−2.1	−4.3	−0.1	+1.4	−3.8	+2.8	+0.8	+2.2	−0.6
Lower Lakes	+2.2	+1.4	−0.3	−2.4	−1.3	−3.9	+0.6	+2.5	−3.1	+2.6	+2.8	+4.4	+0.5
Upper Lakes	+2.5	+2.0	+0.6	−3.5	+0.5	−4.0	−0.1	+1.0	−3.7	+1.6	+2.4	+3.8	+0.3
North Dakota	+8.8	+11.5	+6.2	−4.8	+5.0	−4.4	−0.6	−0.6	−2.8	+0.5	+4.9	+8.5	−2.7
Upper Mississippi Valley	+4.4	+5.4	+3.2	−4.4	+1.7	−5.0	+0.4	+0.9	−3.5	+2.7	+2.3	+4.2	+1.0
Missouri Valley	+6.3	+6.5	+5.3	−3.8	+3.0	−4.8	+0.3	+1.3	−2.4	+2.3	+1.4	+4.9	+1.7
Northern Slope	+5.4	+3.2	−4.8	−2.7	−4.8	−4.5	+0.1	−1.2	−0.4	+0.3	+1.3	−0.6	−0.8
Middle Slope	+6.0	+2.9	−3.1	−2.8	+1.1	−4.5	−0.4	+0.2	−0.4	+2.0	−0.4	+1.8	−0.1
Southern Slope	+2.2	+0.3	+2.8	−2.0	−0.3	+1.0	+0.5	−0.9	−0.7	+3.5	−1.7	+0.2	−0.4
Southern Plateau	+2.6	+0.2	+3.4	+0.2	+2.3	+0.6	+1.3	−0.2	+2.2	+2.0	−0.2	−0.5	−1.2
Middle Plateau	+2.3	+2.6	+3.5	−1.4	+5.7	−0.4	+1.9	+0.2	+2.5	+1.3	+0.1	−3.2	+1.3
Northern Plateau	+0.6	+0.2	+2.8	−2.4	+6.1	−0.7	+3.3	−0.2	+2.1	+1.4	+0.4	−2.7	+0.1
North Pacific	+2.1	+2.0	−3.6	±0.0	+3.5	−0.5	+1.6	±0.0	−0.2	+0.4	+1.2	−0.4	+0.5
Middle Pacific	+0.7	+1.9	+3.4	+0.5	+3.0	+1.3	+0.1	−0.2	+0.4	−0.7	−0.6	−2.1	+0.4
South Pacific	+3.6	+2.7	+3.4	+1.7	+3.0	−0.4	−0.8	−0.9	+1.1	−0.8	+0.9	+0.1	+1.1
UNITED STATES	+2.1	+2.2	+1.3	−2.1	+0.8	−2.0	−0.5	+0.6	−1.0	+1.7	+0.9	+1.4	[1] +0.1

[1] Annual departure.

TABLE 2.—*Monthly and annual precipitation departures, 1928*

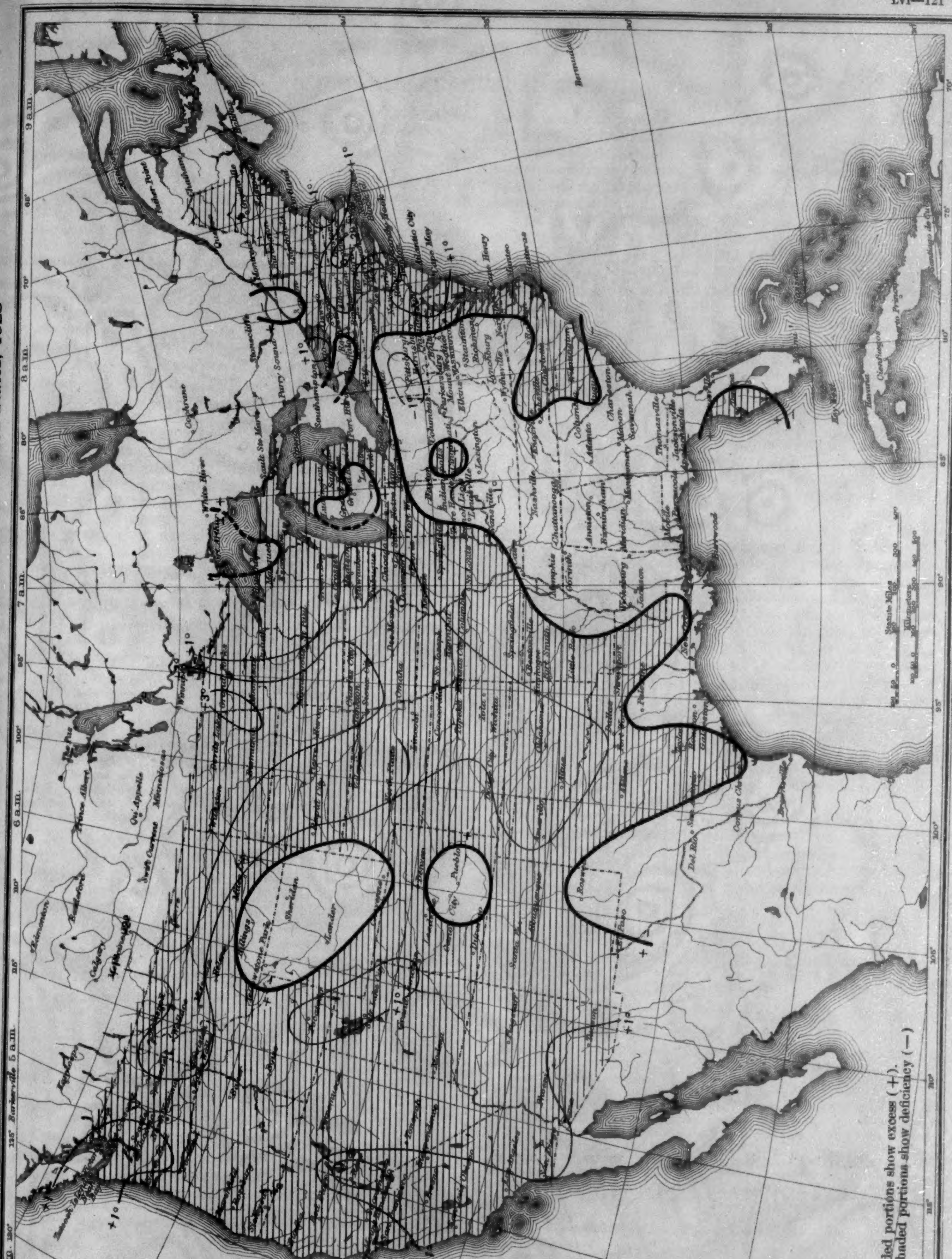
District	January	February	March	April	May	June	July	August	September	October	November	December	Accumulated departures for the year
New England	−1.1	−0.2	−1.0	+0.8	−0.5	+1.2	+0.6	−0.3	+1.1	−1.3	−0.8	−1.2	−2.7
Middle Atlantic	−1.1	−0 3	−0.9	+2.0	−0.9	+2.5	+0 2	+1.7	+1.6	−2.1	−0.8	−1.7	−3.6
South Atlantic	−2.5	+1.2	−0.1	+3.0	±0.0	−1.2	−0.7	+1.5	+7.9	−1.7	−1.1	−0.8	+5.5
Florida Peninsula	−2.1	−1.3	−1.1	±0.0	+0.6	+0.1	−2.7	+1.1	+4.1	−2.3	−1.3	−0.7	−5.6
East Gulf	−3.5	−0.6	+0.5	+3.9	−0.3	+4.0	+0.4	+2.1	−0.5	±0.0	−1.2	−1.9	+2.9
West Gulf	−1.8	+0.8	−1.4	−0.3	−0.9	+1.9	−0 8	−0.7	+1.0	+0.1	+0.1	+1.0	−1.0
Ohio Valley and Tennessee	−1.9	−0.9	−1.3	+0.8	−0.7	+4.5	−0.1	+0.1	−1.6	+1.1	±0.0	−1.4	−1.4
Lower Lakes	−0.7	−0.4	−0.1	+0.1	−1.4	+1.5	+0.8	−0.1	−1.0	±0.0	+0.5	−1.5	−3.3
Upper Lakes	−0.5	−0.4	−0.3	+0.4	−1.2	+1.8	−0.2	+1.0	−0.1	+0.7	+0.2	−0.6	+0.8
North Dakota	−0.4	−0.4	−0.4	−0.7	−1.3	+0.8	+2.6	+1.2	−0.5	−0.8	−0.2	−0.2	−0.3
Upper Mississippi Valley	−1.0	+0.4	−0.8	−0.1	−1.6	+1.4	+0.4	+2.4	−1.0	+1.2	+1.4	−0.1	−2.6
Missouri Valley	−0.8	+0.3	−0.9	−0.8	−1.4	+2.0	−0.3	+0.5	−1.1	+0.8	+2.2	−0.1	+0.4
Northern Slope	−0.4	−0.4	−0.2	−0.8	−0.9	+1.3	+0.7	−0.5	−0.8	+0.4	±0.0	−0.4	−2.0
Middle Slope	−0.5	+0.5	+0.1	+0.2	−0.9	+2.0	±0.0	−0.4	−1.4	+0.6	+1.8	±0.0	−2.0
Southern Slope	−0.3	±0.0	−0.5	−1.1	+3.3	−0.5	−0.2	+2.2	±0.0	+0.2	±0.0	−0.3	−2.8
Southern Plateau	−0.7	+0.3	−0.1	±0.0	+0.5	−0.4	−0.8	+0.3	−0.7	+0.4	−0.1	−0.3	−1.0
Middle Plateau	−0.7	−0.9	+0.7	−0.4	−0.1	−0.1	−0.1	−0.3	−0.5	+0.3	±0.0	−0.3	−2.4
Northern Plateau	+0.2	−1.1	+0.4	−0.4	−1.3	−0.3	+0.2	−0.4	−0.4	−0.4	−0.6	−0.6	−4.7
North Pacific	−0.7	−3.3	+2.9	+0.8	−1.4	−1.1	−0.3	−0.7	−1.3	+0.5	−2.3	−2.8	−9.7
Middle Pacific	−2.6	−2.1	+0.8	+0.2	−0.9	−0.2	±0.0	±0.0	−0.5	−0.8	+1.1	+0.1	−4.9
South Pacific	−2.1	−1.2	−0.7	−0.7	−0.2	−0.1	±0.0	±0.0	−0.2	−0.5	+0.3	+0.2	−5.2
UNITED STATES	−1.2	−0.5	−0.2	+0.3	−0.5	+1.0	±0.0	+0.5	+0.2	−0.2	±0.0	−0.6	−1.2

TABLE 3.—*Number of cyclones and anticyclones [1] plotted in 1928, with apparent place of origin*

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Extra tropical cyclones:													
Canada	8	7	4	3	5	2	2	0	4	7	5	5	52
Northern Pacific	0	2	2	2	1	0	0	0	0	0	2	3	12
United States	7	5	7	9	9	7	7	9	8	7	3	2	80
Tropical cyclones								3	1				4
Total	15	14	13	14	15	9	9	12	13	14	10	10	148
Anticyclones:													
Canada	4	5	7	7	7	1	6	3	6	5	5	1	57
Northern Pacific	3	5	1	1	3	0	0	0	2	0	2	2	19
United States	6	3	2	2	3	4	3	7	3	8	3	3	47
Total	13	13	10	1 0	13	5	9	10	11	13	10	6	123

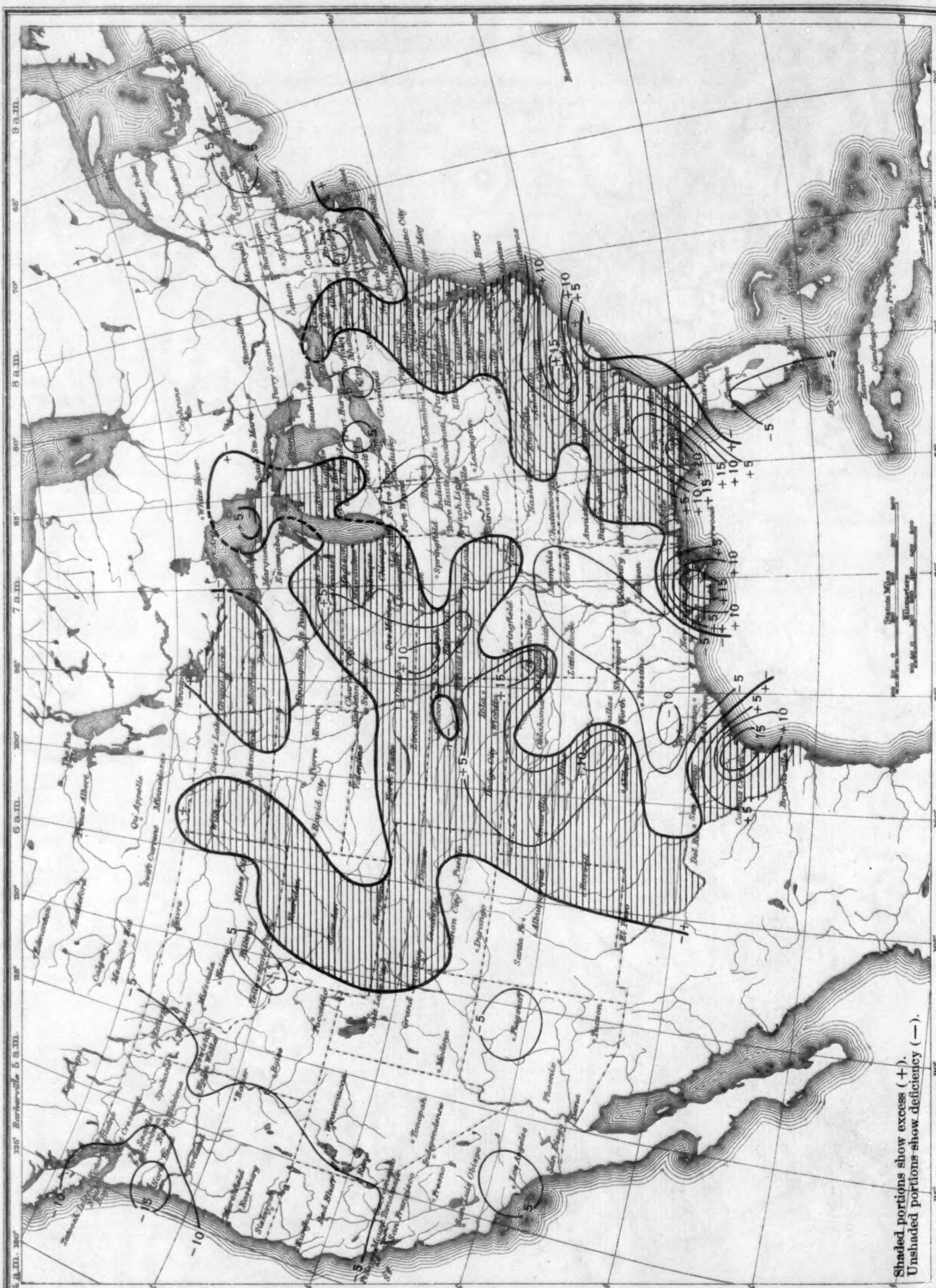
[1] Including secondaries of both but does not include cyclones that traversed the Atlantic off the east coast of United States.

A. J. H. I. Annual Temperature Departures (°F.) in the United States, 1928



Shaded portions show excess (+).
Unshaded portions show deficiency (−)

A. J. H. **II. Annual Precipitation Departures (inches) in the United States, 1928**



Shaded portions show excess (+).
Unshaded portions show deficiency (−).

NOTES, ABSTRACTS, AND REVIEWS

CLASSIFICATION OF MONTHLY CHARTS OF PRESSURE ANOMALY OVER THE NORTHERN HEMISPHERE [1]

By C. E. P. BROOKS, M. Sc., and WINNIFRED QUINNELL

For a long time I have had a very lively interest in the study of weather abnormalities in various parts of the world, not only by reason of the importance of such a study of weather phenomena, but also because eventually such studies may form the approach to the solution of the larger problem of seasonal weather forecasting. If, and when, weather abnormalities can be forecast the problem of seasonal forecasts will easily follow. I therefore, welcome the memoir here abstracted. The authors selected the period 1873 to 1900 and 114 stations, mostly in the Northern Hemisphere, as the groundwork for their study. They have used departures from normal pressure rather than charts of monthly isobars.—*Ed.*

The 336 charts for the years 1873 to 1900 were divided into two groups, according to whether pressure at Thorshavn was above or below the normal for the month. When the pressure at that station in any month was very nearly normal the chart for that month was allocated to the positive group if the oceanic region between Iceland and the British Isles was dominated by a positive anomaly of pressure (center of excess) and to the negative group if it was dominated by a negative anomaly (center of deficit).

These two groups were next divided into five types according to the position of the center of the anomaly as shown in the scheme below:

GROUP I. PRESSURE AT THORSHAVN ABOVE NORMAL	GROUP II. PRESSURE AT THORSHAVN BELOW NORMAL
IA. Center of excess over or near Scandinavia.	IIA. Center of deficit over or near Scandinavia.
IB. Belt of excess from British Isles across Europe.	IIB. Belt of deficit from British Isles across Europe.
IC. Center of excess over British Isles.	IIC. Center of deficit over British Isles.
ID. Center of excess over Iceland or southern Greenland.	IID. Center of deficit over Iceland or southern Greenland.
IE. Pressure above normal over the Arctic generally; belt of deficit across the Atlantic and southern Europe in 40–50 N.	IIE. Pressure below normal over the Arctic generally; belt of excess across the Atlantic and Mediterranean in about 40 N.

The sequence of types in successive months which, parenthetically is the most important part of the discussion, is given in Table 4, and this table also gives in italics the frequency which would be expected if the distribution were due purely to chance, the actual occurrences being in roman. The figures are further divided into seasons, winter, October to March, and summer, April to September. The authors comment on these figures as follows:

> A comparison of the roman and italic figures shows very little indication of any ordered sequence. There is a slight tendency for the persistence of types from one month to the next, the same type occurring in two successive months in 44 cases in winter and 41 in summer, compared with an expectancy of 35 and 36, respectively; type IC (center of excess over British Isles) is especially persistent in winter. Type ID in summer tends to be followed by either ID or IC. Type IIC (center of deficit over British Isles) in winter tends to be followed by Group I (pressure above normal at Thorshavn), this sequence occurring on 25 occasions out of 31.

The tendency of certain weather types to persist as mentioned in the above paragraph is in all probability a world-wide phenomenon and is more highly developed in high than in low latitudes. The British Isles and Scandinavia are examples of a maximum development of this tendency. In the United States a single type of cyclonic movement occasionally dominates the weather for a period as long as two months in the cold season. Marked abnormalities in temperature in the same sense may be experienced over a period as long as three to four months.

The 10 types as above outlined were next divided into a number of subtypes. This process was initially empirical, the charts of each type being sorted and arranged until a number of sets were obtained, the members of each set being characterized by a certain family likeness. When this was done each set was examined to find points in common that could be used as a basis of classification, and the final allocation was made on the basis of classification thus obtained.

The number of charts that was allocated to each subtype naturally varied somewhat. Types IID, ID, and IC occur most frequently, these types accounting for half of the months.

Subtype IID, as already shown, consists of a center of pressure deficit over Iceland or south Greenland, and subtype ID the reverse, that is, a center of pressure excess instead of deficit; subtype IC has the excess of pressure anomaly over the British Isles.

The authors remark: "In view of the great variability of pressure in the Icelandic region, the frequency of subtypes IID and ID deficit or excess of pressure centered near Iceland is to be expected, the frequency of subtype IC (excess centered over British Isles) is more surprising."

The type of pressure anomaly for each month of the period 1873 to 1918 is given in tabular form with the months of uncertain classification given in parentheses and the months with an anomaly exceeding 10 millibars in bold faced type. Concerning the latter it is rather surprising to find that the pressure anomaly is greater than 10 millibars in the Icelandic region 77 per cent of the time in February, 65 in January, 63 in March, and 56 in December.

The memoir contains a series of 36 greatly reduced Northern Hemisphere charts showing typical cases of pressure anomalies.

The impression that one gets from these charts is that the large fluctuations of pressure are confined, in the main, to high latitudes and that there is need of much more data both from continental and oceanic areas before the delimitation of regions of pressure abnormalities can be accurately fixed.—*A. J. H.*

SHORT-WAVE ECHOES AND THE AURORA BOREALIS [1]

By CARL STORMER

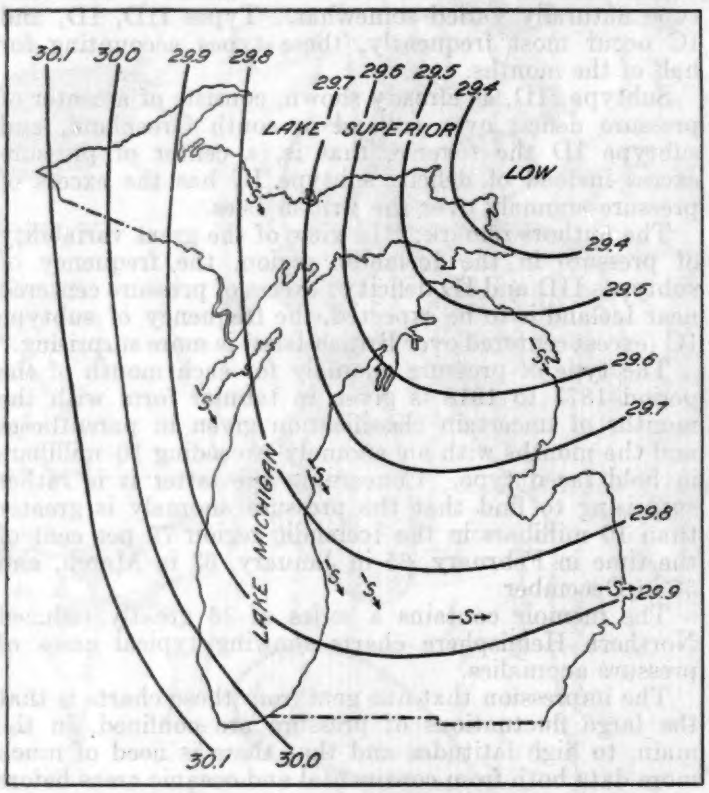
On February 29 of this year I received a letter from Engineer Jørgen Hals, Bygdø, Oslo, in which he says:

> I herewith have the honor to advise you that at the end of the summer 1927, I repeatedly heard signals from the Dutch short-wave transmitter station PCJJ (Eindhoven). At the same time as I heard the telegraph signals I also heard echoes. I heard the usual echo, which goes round the earth with an interval of about one-seventh second, as well as a weaker echo about 3 seconds after the principal signal had gone. When the principal signal was especially strong, I suppose that the amplitude for the last echo 3 seconds after, lay between one-tenth and one-twentieth of the principal signal in strength. From where this echo comes I can not say for the present. I will only herewith confirm that I really heard this echo.

[1] Meteorological Office, Geophysical Memoirs No. 31 (first number of Volume IV).

[1] Reprinted from Nature, London, November 3, 1928, p. 681.

Immediately I heard of this remarkable observation, it struck me that the wireless waves were reflected from those streams and surfaces of electrons to which I was led by theoretical investigations on the aurora borealis in my paper published in 1904 in Videnskabsselskabets Skrifter, Christiania ("Sur le mouvement d'un point matériel portant une charge d'électricité sous l'action d'un aimant élémentaire"). In reference to that paper, and the subsequent more complete one in Archives des Sciences physiques et naturelles, Geneva, 1907, one of the most striking features of the theory was that streams of electrons coming from without toward the earth were deviated by the earth's magnetic field in such a way that an immense space was formed free from electric particles, and having the shape of a torus described by revolution of an oval tangent to the magnetic axis of the earth at the center. These results were also in full agreement with



Typical pressure condition favorable for snow squalls over Michigan.

Kr. Birkeland's remarkable experiments with cathode rays directed toward a magnetic sphere, described in 1901 in Videnskabsselskabets Skrifter ("Expedition norvégienne de 1899–1900 pour l'étude des aurores boréales"). If now the wireless signals could penetrate the Heaviside layer, they would pass into this empty space, and might be reflected by the walls of the electrons forming its outer boundary. The long time interval between the principal signal and the echo agrees well with the immense dimensions of these toroidal spaces.

It was now very interesting to me to obtain more evidence of these remarkable echoes, and last spring and summer I organized a long series of observations, for which I am very much indebted to Dr. van der Pol, at Philips Radio, Eindhoven, for his very efficient work in sending signals, and further to Elektrisk Bureau, Oslo, to the Norwegian Telegraph Administration, and to Engineer Hals, for aid in arranging the reception of the signals. The observations were continued during October but no certain evidence was obtained before October 11. Eindhoven emitted during the afternoon very strong signals of undamped waves of wave-length 31.4 meters, and Hals and I heard very distinct echoes several times, the interval between signal and echo varying between 3 and 15 seconds, most of them coming about 8 seconds after the principal signal. Sometimes two echoes were heard with an interval of about 4 seconds. I immediately telegraphed the success to Dr. van der Pol at Eindhoven, and asked him to control and verify the effect. Next day I received the following telegram:

> Last night special emission gave echoes here varying between 3 and 15 seconds stop 50 per cent of echoes heard after 8 seconds stop van der Pol.

After this it seems that we have here a new and remarkable phenomenon, the study of which may throw much new light on the electric currents in space outside the earth and on their connection with the aurora borealis and magnetic storms. The variability of the phenomenon indicated by the observations agrees well with the corresponding variability of aurora and the magnetic registrations.

Snow squalls of the Lake region (by R. M. Dole, Weather Bureau, Lansing, Mich.)—Cold air flowing over warm water creates clouds, and as a result the land to the leeward of the wind is cloudy as long as the contrast in temperature is marked. Michigan, for instance, is covered with a cloud sheet from November to May, and the sunshine is markedly deficient during these months.

In spring and fall and often in winter snow squalls occur when high pressure brings in cold air, which blows over the warm lake waters. The difference in temperature must be somewhat marked, and there must be a rather steep barometric gradient. This often occurs when a low pressure system with circular isobars crosses the Great Lakes, and when the barometric lines run north-south or even northwest-southeast. The cold air crossing the warm Lake Michigan builds up enormous clouds, which are very similar to thunderstorms in appearance and sometimes are electrical. The tops rise to a considerable height with false cirrus and blue-black curtain clouds, out of which drifts snow, and if it is cold enough this snow reaches the surface in the form of snow squalls. These snow squalls are quite the regular thing in the spring, fall, and often in the winter.

The snow squall condition is of the utmost importance to flying, because the visibility is very low—often only 10 feet—and the wind is strong and often dangerous. The squalls are of short duration and after passing, the sun comes out for a few moments until the next squall arrives. The pilot, of course, with any weather sense can readily see these squalls coming 15 miles away because of their great heads and silver crests, but it is practically impossible to dodge them; the pilot can only dodge the strong squally portion by flying to the left of the curtain cloud.

The snow squall condition obtains after the storm proper is just east of Lake Michigan and often when the storm has passed down the St. Lawrence Valley. The conditions which are ripe for squalls are a marked contrast in temperature and the lines running nearly north-south, so that the wind is anywhere between west-northwest to north-northeast. Very often the sky is clear at sunrise but by 9 to 11 a. m. cumulus clouds are noted on the northern horizon, and under the influence of a strong sun in a clear sky they build up enormously.

The influence of the sun is necessary, and the squalls disappear as soon as the sun has set as a rule. Squalls do not obtain when a uniform sheet of stratus covers the sky.

The charts given show typical instances when snow squalls were general over Michigan, and a marked similarity will be noticed in the trend of the isobaric lines, and squalls will occur whenever there is a similar distribution of pressure with lines running north-south. In looking over the old records of Michigan weather these squalls were noted all through the history of past conditions, and in many instances the winds were termed dangerously strong and the snow as very thick.

Not only does the rather round low pressure area with lines running roughly north-south produce snow squalls in the fall, winter and spring, but it causes clearing weather to be delayed from 12 hours to several days after the pressure has begun to rise. Precipitation, either as a steady fall or in the form of sun showers, is the usual thing, and it is most exasperating to forecasters as well as to the public. Rising pressure which would be certain fair weather anywhere away from the water is just the opposite in the Lake Region.

The anticyclones of December, 1928.—Two of the anticyclones of this month call for special note, the first was centered over the Lander (Wyo.) station, from the 4th to the 10th, both inclusive. It was doubtless formed originally by a flow of polar air on the 3d and 4th. Thereafter it was maintained largely by intense terrestrial radiation and the drainage of cold air into the depression in which the Lander station is situated. Two secondary anticyclones were discharged from this anticyclone, the first on the 5th, and this one was doubtless a result of the eastward flow of a part of the original mass of polar air. The second one was pinched off on the 7th when a ridge of cold air over western Nebraska and Kansas became separated from the original mass.

The Great Basin anticylone discharged but a single secondary; the latter took a course to the southeastward over New Mexico and moved thence to the Atlantic. Pressure in all of the secondaries diminished as they crossed the Mississippi Valley and again increased where they crossed the Appalachians, although in no case could they be considered as being composed of polar air.—*A. J. H.*

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SOLAR OBSERVATIONS

SOLAR AND SKY RADIATION MEASUREMENTS DURING DECEMBER, 1928

By HERBERT H. KIMBALL, Solar Radiation Investigations

For a description of instruments and exposures and an account of the method of obtaining and reducing the measurements, the reader is referred to the REVIEW for January, 1924, 52:42; January, 1925, 53:29, and July, 1925, 53:318.

Table 1 shows that solar radiation intensities averaged slightly below normal values for December at Washington, D. C., and Lincoln, Nebr. At Madison, Wis., but few measurements were made.

Table 2 shows that the total solar radiation received on a horizontal surface directly from the sun and diffusely from the sky was below the December normal at the three stations for which normals have been determined. For the year the total received was slightly below the annual average for the respective stations.

Skylight polarization measurements, made at Washington on three days, give a mean of 56 per cent, with a maximum of 60 per cent on the 11th. These are slightly below the corresponding average values for Washington in December. At Madison no measurements were obtained during the month, as most of the time the ground was covered with snow.

TABLE 1.—*Solar radiation intensities during December, 1928*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance: 8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass, A. M.: 5.0	4.0	3.0	2.0	[1]1.0	P. M.: 2.0	3.0	4.0	5.0	Local mean solar time
	e.										e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Dec. 3	5.16				1.07			0.90			6.27
Dec. 4	4.37			0.98	1.26						4.17
Dec. 5	6.76			1.19	1.31						3.45
Dec. 6	2.26	0.57	0.70	0.90	1.26			1.04	0.91	0.84	1.65
Dec. 10	1.96	0.73	0.82	0.95	1.08			0.87			2.26
Dec. 11	3.15	0.84	0.98	1.11	1.28			1.12	0.97	0.83	2.06
Dec. 13	4.57	0.36	0.49	0.67							5.16
Dec. 18	3.45			1.06				1.00	0.97	0.82	2.49
Dec. 19	3.45	0.88	0.95	1.15	1.35			1.18	1.00		2.74
Dec. 21	1.88	0.92	1.04	1.19	1.38			1.10	0.96		1.12
Dec. 22	1.88			0.71	0.82						1.37
Dec. 26	3.81			0.60	0.77						3.81
Means		0.72	0.83	0.96	1.16			1.04	0.92	0.83	
Departures		−0.06	−0.06	−0.08	−0.07			+0.01	+0.01	+0.04	

Madison, Wis.

Date	8 a.m.	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	Noon
Dec. 21	0.74		1.12	1.31							0.96
Means			(1.12)	(1.31)							
Departures			+0.02	+0.09							

Lincoln, Nebr.

Date	8 a.m.	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	Noon
Dec. 4	1.60							1.14	1.07	0.95	1.68
Dec. 5	2.16	0.90	1.04	1.16	1.22						2.16
Dec. 6	2.87		0.95	1.19	1.38			1.03	0.87		2.62
Dec. 19	2.06	1.14	1.22	1.35	1.49						1.87
Dec. 22	3.45			1.14	1.33			1.11	1.02		3.81
Dec. 24	3.81		1.01	1.20				1.22	1.13	0.99	3.99
Dec. 26	3.00							1.02	0.90	0.82	3.15
Dec. 27	4.37	0.95	1.07	1.14							3.15
Dec. 29	2.74	1.03	1.15	1.26							3.15
Means		1.00	1.07	1.21	1.36			1.10	1.00	0.92	
Departures		−0.05	±0.00	−0.01	−0.02			−0.09	−0.07	−0.04	

[1] Extrapolated.

TABLE 2.—*Solar and sky radiation received on a horizontal surface*

[Gram-calories per square centimeter of horizontal surface]

Week beginning	Average daily radiation: Washington	Madison	Lincoln	Chicago	New York	Average daily departure from normal: Washington	Madison	Lincoln
1928	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Dec. 3	190	136	210	95	77	+45	+12	+37
10	122	73	84	49	95	−18	−44	−82
17	136	116	152	80	94	−6	−8	−13
24 [1]	120	109	182	79	94	−23	−20	+8
Deficiency at end of year						−1,740	−906	−2,260

[1] 8-day period.

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. C. S. Freeman, Superintendent U. S. Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, and Mount Wilson Observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time	Heliographic: Diff. long.	Longitude	Latitude	Area: Spot	Group	Total area for each day
1928	h. m.	°	°	°			
Dec. 1 (Mount Wilson)	11 00	−68.0	250.6	+11.0	8		
		−61.0	257.6	−15.0	174		
		−50.0	268.6	+9.0		459	
		−27.0	291.6	+14.0	3		
		−17.0	301.6	+9.0		4	648
Dec. 2 (Naval Observatory)	11 42	−47.5	257.6	−16.5	123		
		−39.5	265.6	+9.0		463	
		−2.0	303.1	+8.0		31	
		−1.0	304.1	+22.0		62	
		+0.5	305.6	−2.5	6		685
Dec. 3 (Naval Observatory)	11 41	+35.0	256.9	−16.5	123		
		−26.0	265.9	+8.5		772	
		−7.5	284.4	+10.0	6		
		+11.0	302.9	+8.0	9		
		+13.0	304.9	+22.0		46	956
Dec. 4 (Naval Observatory)	11 41	−42.5	236.3	−11.5		123	
		−21.5	257.3	−17.5	123		
		−12.0	266.8	+8.5		833	
		+27.5	306.3	+21.0		46	1,125
Dec. 5 (Naval Observatory)	11 45	−28.5	237.1	−11.5		247	
		−8.5	257.1	−17.5	123		
		+0.5	266.1	+8.0		1,049	
		+40.0	305.6	+21.0		31	1,450
Dec. 6 (Naval Observatory)	11 49	−79.0	173.3	−11.5		154	
		−15.5	236.8	−11.5		231	
		−7.0	245.3	+11.5		46	
		+4.0	256.3	−17.5	123		
		+14.5	266.8	+8.0		988	1,542
Dec. 7 (Mount Wilson)	14 00	−67.0	171.0	−9.0	63		
		−63.0	175.0	+20.0	4		
		−2.0	236.0	−10.0		251	
		+18.0	256.0	−18.0	126		
		+30.0	268.0	+8.0		530	974
Dec. 8 (Naval Observatory)	9 57	−52.5	174.5	−11.5		93	
		+10.0	237.0	−11.5		278	
		+29.5	256.5	−17.5	123		
		+40.0	267.0	+8.0		848	1,342
Dec. 9 (Naval Observatory)	12 23	−78.0	134.5	+14.0	31		
		−39.5	173.0	−11.0		108	
		−37.5	175.0	+18.0		31	
		−22.5	190.0	+15.0	15		
		+24.0	236.5	−11.5		432	
		+42.5	255.0	−17.0	123		
		+56.0	268.5	+7.5		910	1,650
Dec. 10 (Naval Observatory)	11 52	−88.0	111.6	+14.5	154		
		−65.5	134.1	+14.0	31		
		−29.0	170.6	−17.0	12		
		−27.0	172.6	−11.0		154	
		−24.0	175.6	+18.5		62	
		−23.5	176.1	+12.0		46	
		+37.5	237.1	−11.5		370	
		+56.0	255.6	−17.0	139		
		+70.5	270.1	+7.5		1,173	2,141

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard civil time		Heliographic			Area		Total area for each day
			Diff. long.	Longitude	Latitude	Spot	Group	
1928	h.	m.	°	°	°			
Dec. 11 (Naval Observatory).	11	49	−82.0	104.5	+15.0		93	
			−73.5	113.0	+15.0	185		
			−51.5	135.0	+14.5	31		
			−14.5	172.0	−11.0		139	
			−9.5	177.0	+18.5		77	
			−8.5	178.0	+12.5		9	
			+52.0	238.5	−11.0		432	
			+71.0	257.5	−16.5	123		
			+80.0	266.5	+8.0		340	1,429
Dec. 12 (Naval Observatory).	10	34	−68.0	106.0	+14.0		77	
			−60.0	114.0	+15.5	231		
			−38.5	135.5	+14.0	31		
			−29.0	145.0	−14.5		31	
			0.0	174.0	−10.5		139	
			+2.5	176.5	+18.5		123	
			+8.0	182.0	+12.0	6		
			+15.0	189.0	−14.5	9		
			+26.0	200.0	+14.5	12		
			+65.0	239.0	−11.5		355	
			+86.0	260.0	−17.0	123		1,137
Dec. 13 (Naval Observatory).	12	32	−85.0	74.7	+23.5		108	
			−70.0	89.7	−20.0	31		
			−54.0	105.7	+14.5		31	
			−45.5	114.2	+15.0	170		
			−24.0	135.7	+14.5	25		
			−15.5	144.2	−14.5		31	
			+15.5	175.2	−10.0		108	
			+18.5	178.2	+19.0		108	
			+23.0	182.7	+12.5		62	
			+29.0	188.7	−14.5		46	
			+80.5	240.2	−11.5		386	1,106
Dec. 14 (Harvard)	13	15	−68.5	77.5	+23.5		92	
			−55.0	91.0	−19.5	28		
			−31.5	114.5	+17.0	278		
			−11.5	134.5	+7.0		31	
			+29.0	175.0	−8.0	70		
			+35.0	181.0	+13.5		248	
			+35.0	181.0	+20.0		117	
			+43.5	189.5	−12.5	21		885
Dec. 15 (Naval Observatory).	11	46	−56.0	77.8	+23.0	31		
			−44.5	89.3	−19.5		46	
			−24.0	109.8	−15.0		31	
			−19.0	114.8	+16.0	154		
			−5.0	128.8	−13.0	6		
			+3.0	136.8	+5.5		46	
			+14.0	147.8	−14.0	6		
			+42.5	176.3	−9.5	62		
			+45.0	178.8	+19.0		77	
			+49.0	182.8	+12.5		247	
			+59.5	193.3	−14.0	15		721
Dec. 16 (Naval Observatory).	11	47	−52.0	68.6	−20.5		31	
			−42.0	78.6	+22.0	25		
			−32.0	88.6	−19.0		62	
			−6.5	114.1	+15.5	139		
			+12.0	132.6	−10.5		28	
			+17.0	137.6	+5.0		46	
			+57.5	178.1	−9.5	46		
			+61.5	182.1	+12.5		309	
			+62.0	182.6	+18.0	31		717
Dec. 17 (Mount Wilson)	14	15	−27.0	79.1	+22.0	4		
			−7.1	90.0	−9.6	2		
			+8.0	114.1	+15.0	93		
			+27.2	133.3	−9.8	2		
			+30.5	136.6	+4.9		2	
			+70.0	176.1	−10.0	30		
			+72.0	178.1	+13.0		187	320
Dec. 18 (Naval Observatory).	11	52	−15.0	79.2	+22.5	25		
			+20.0	114.2	+16.5	139		
			+41.0	135.2	−9.0	25		
			+45.0	139.2	+5.0		15	204
Dec. 19 (Naval Observatory).	11	46	−2.0	79.1	+22.0	9		
			+32.5	113.6	+15.5	108		
			+42.0	123.1	+7.0	18		135
Dec. 20 (Mount Wilson)	11	10	−18.0	50.2	−9.0	4		
			−9.0	50.2	+8.0		10	
			+10.0	78.2	+21.0	6		
			+19.0	87.2	−18.0	4		
			+45.0	113.2	+15.0	154		178
Dec. 21 (Naval Observatory).	11	46	+24.5	79.2	+21.5	6		
			+56.0	110.7	−16.0	46		
			+60.0	114.7	+15.0	139		191
Dec. 22 (Naval Observatory).	11	46	−13.0	28.6	+10.5		46	
			+70.0	111.6	−15.0	62		
			+72.0	113.6	+15.5	123		231
Dec. 23 (Naval Observatory).	13	20	+1.5	29.0	+10.0		62	62
Dec. 24 (Naval Observatory).	12	44	−22.5	352.2	+9.0		25	
			+15.0	29.7	+10.5		46	71
Dec. 25 (Naval Observatory).	12	46	−80.0	281.5	+9.0		340	
			−8.0	353.5	+9.0	18		358
Dec. 26 (Naval Observatory).	11	56	−77.0	271.8	+11.5		525	
			−68.0	280.8	+8.5		185	
			+5.5	354.3	+8.5		15	725
Dec. 28 (Naval Observatory).	11	49	−50.0	272.5	+10.5		340	
			−36.0	286.5	+8.0		154	
			−3.5	319.0	+4.0		31	
			+32.5	355.0	+7.5	15		540
Dec. 29 (Mount Wilson)	14	00	−71.0	237.2	−10.5	60		
			−35.0	273.2	+10.0		106	
			−20.0	288.2	+7.5		405	
			+15.0	323.2	+5.0		46	617
Dec. 30 (Mount Wilson)	14	30	−58.0	236.7	−10.0	55		
			−22.0	272.7	+10.0		285	
			−5.0	289.7	+8.5		271	
			+30.0	324.7	+4.5		106	717
Dec. 31 (Naval Observatory).	11	49	−44.5	238.5	−11.0		77	
			−9.5	273.5	+10.0		154	
			+7.0	290.0	+8.0		324	
			+23.5	306.5	+20.0		46	
			+42.0	325.0	+4.5		62	663
Mean daily area for December								784

PROVISIONAL SUNSPOT RELATIVE NUMBERS FOR DECEMBER, 1928

[Data furnished by Prof. W. Brunner, University of Zurich, Switzerland]

December, 1928	Relative numbers	December, 1928	Relative numbers	December, 1928	Relative numbers
1		11	87	21	25
2	55	12		22	
3	64	13		23	23
4	95	14		24	16
5	128	15	101	25	8
6	95	16	89	26	13
7	94	17	56	27	31
8	85	18		28	37
9	77	19		29	53
10	94	20	32	30	61
				31	71

Number of observations, 24; mean, 62.1.

AEROLOGICAL OBSERVATIONS

By L. T. SAMUELS

A striking example of a marked increase in free-air temperatures while winds remained northwesterly throughout the period was revealed by the morning kite records of Ellendale on December 4 and 5. During this 24-hour interval the temperature rose 9° C. at 1,000 meters, 12° C. at 2,000 meters, and 11° C. at 3,000 meters. In explanation thereof it may be stated that the air arriving over Ellendale on the 4th was apparently coming directly from a high-pressure area centered over Montana, whereas that on the 5th came from the rear of a secondary low forming on the rear of a primary depression centered over Ontario. Twenty-four hours later, on the 6th, this secondary remained practically unchanged and free-air temperatures at Ellendale continued relatively high.

An unusually deep layer of saturated air occurred over Due West on the morning of the 17th. With fog at the surface the kite record showed a practically saturated condition up to an altitude of 2,170 meters, where an abrupt surface of discontinuity occurred and the temperature rose 6° C. within the next 120 meters, while the relative humidity dropped from 100 to 16 per cent. The average lapse rate throughout this saturated air column was 0.74° C. per 100 meters. This condition occurred in the front of a long trough of low pressure.

Table 1 shows some striking contrasts in the free-air temperatures at the various stations. At Ellendale and Royal Center, the two northernmost stations, these departures were all positive and of considerable magnitude, especially in the lower levels. At Due West and Groesbeck the temperatures were practically all below normal with the greatest departures occurring in the upper levels.

Free-air relative humidities were below normal at practically all stations and levels, the most striking instance being at Due West, where the negative departures were appreciable notwithstanding the large free-air temperature deficiency at this station. In view of this abnormal relationship it is not surprising to find a deficiency in the total precipitation for the month, viz, 1.20 inches, which is the lowest on record for December at this station.

Resultant winds (Table 2) for the month conform in general with the temperature departures, particularly at Due West, where a pronounced northerly component predominated instead of the normal southerly component. Resultant velocities were close to normal at practically all stations and levels.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during December, 1928*

TEMPERATURE (° C.)

Altitude m. s. l.	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center, Ind. (225 meters)	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Meters										
Surface	4.8	+0.6	6.6	−1.4	−5.9	+3.6	8.2	−0.9	1.3	+3.0
250	4.8	+0.6	6.5	−1.4			8.5	−0.5	1.2	+3.0
500	4.5	+0.8	6.3	−1.3	−5.8	+3.6	8.8	+0.2	0.0	+3.0
750	4.2	+0.7	6.0	−1.4	−4.5	+3.8	8.9	+0.5	−0.9	+2.6
1,000	3.9	+0.7	5.3	−1.7	−4.0	+3.1	8.3	−0.2	−1.6	+2.0
1,250	3.5	+0.5	4.5	−1.9	−4.4	+2.2	7.6	−0.6	−2.2	+1.4
1,500	2.9	+0.1	3.6	−2.0	−5.0	+1.6	7.1	−0.6	−2.6	+1.2
2,000	1.0	−0.5	1.9	−2.1	−6.3	+1.4	5.5	−0.7	−3.9	+1.1
2,500	−0.6	−0.1	−0.2	−2.3	−8.6	+1.1	3.3	−0.9	−6.2	+0.6
3,000	−2.7	+0.1	−3.1	−3.0	−10.4	+1.8	1.2	−0.7	−8.4	+0.6
3,500	−5.5	−0.3	−6.0	−3.6	−13.0	+1.9	−1.4	−0.8	−10.4	+1.2
4,000	−8.8	−0.7	−9.7	−4.4	−16.0	+1.7	−4.4	−1.1	−13.2	+1.5
4,500			−13.4	−4.9	−17.6	+2.6	−6.4	−0.7		

RELATIVE HUMIDITY (%)

Altitude m. s. l.	Broken Arrow Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure
Surface	67	−3	70	−2	77	−4	73	−1	76	−4
250	67	−3	69	−2			68	−3	76	−4
500	63	−2	59	−6	75	−4	59	−8	75	−3
750	59	−1	54	−8	66	−5	51	−12	75	+1
1,000	55	+1	51	−9	61	−3	46	−11	73	+5
1,250	53	+5	51	−8	59	−1	42	−11	66	+4
1,500	50	+6	51	−7	56	−1	37	−12	60	+2
2,000	44	+5	46	−8	49	−5	28	−14	54	0
2,500	36	−1	39	−10	50	−4	25	−14	52	−1
3,000	35	−2	37	−7	46	−7	18	−18	54	+1
3,500	27	−8	36	−8	38	−15	15	−18	39	−12
4,000	27	−8	35	−8	35	−17	23	−12	41	−13
4,500			34	−7	17	−29	19	−16		

VAPOR PRESSURE (mb.)

Altitude m. s. l.	Broken Arrow Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure
Surface	5.82	−0.45	7.25	−1.21	3.13	+0.45	8.42	−1.01	5.32	+0.69
250	5.79	−0.43	7.11	−1.25			8.03	−1.05	5.27	+0.70
500	5.29	−0.27	6.17	−1.49	3.09	+0.45	7.15	−1.17	4.84	+0.79
750	4.75	−0.25	5.54	−1.62	2.83	+0.31	6.15	−1.47	4.57	+0.88
1,000	4.26	−0.20	4.93	−1.67	2.52	+0.10	5.24	−1.53	4.16	+0.83
1,250	4.04	+0.10	4.61	−1.54	2.36	+0.04	4.60	−1.43	3.55	+0.55
1,500	3.73	+0.16	4.32	−1.31	2.16	−0.03	3.85	−1.41	3.12	+0.38
2,000	2.97	+0.08	3.33	−1.24	1.73	−0.14	2.47	−1.49	2.56	+0.27
2,500	1.98	−0.38	2.17	−1.43	1.49	−0.09	1.90	−1.26	2.10	+0.14
3,000	1.51	−0.48	1.75	−1.12	1.20	−0.06	1.20	−1.34	1.77	+0.07
3,500	0.88	−0.79	1.39	−1.13	0.88	−0.09	0.97	−1.03	0.91	−0.46
4,000	0.56	−0.86	1.04	−1.00	0.72	−0.06	1.03	−0.82	0.84	−0.35
4,500			0.76	−0.69	0.61	+0.03	0.72	−0.90		

TABLE 2.—*Free-air resultant winds (m. p. s.) during December, 1928*

Altitude m. s. l. (meters)	Broken Arrow, Okla. (233 meters)				Due West, S. C. (217 meters)			
	Mean		Normal		Mean		Normal	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°	
Surface	S. 41 W.	0.9	S. 63 W.	1.1	N. 66 W.	0.6	S. 73 W.	1.0
250	S. 50 W.	1.0	S. 55 W.	1.2	N. 52 W.	0.6	S. 68 W.	1.1
500	S. 50 W.	2.5	S. 49 W.	2.9	N. 24 W.	1.7	S. 69 W.	2.8
750	S. 60 W.	3.5	S. 55 W.	3.8	N. 42 W.	2.4	S. 74 W.	4.4
1,100	S. 78 W.	3.9	S. 67 W.	4.3	N. 58 W.	3.0	S. 80 W.	5.8
1,250	S. 79 W.	4.2	S. 77 W.	5.0	N. 59 W.	4.2	S. 80 W.	7.3
1,500	S. 87 W.	5.2	S. 80 W.	5.9	N. 65 W.	5.2	S. 85 W.	8.8
2,000	N. 82 W.	4.3	S. 85 W.	7.1	N. 78 W.	8.5	S. 86 W.	11.0
2,500	N. 79 W.	5.8	N. 88 W.	9.2	N. 82 W.	10.2	S. 89 W.	11.6
3,000	N. 76 W.	7.2	N. 88 W.	10.4	N. 67 W.	10.6	N. 85 W.	13.2
3,500	N. 80 W.	8.3	N. 88 W.	12.1	N. 47 W.	8.4	N. 82 W.	13.0
4,000	N. 74 W.	6.8	N. 85 W.	11.7	N. 11 W.	15.7	N. 71 W.	12.0
4,500	S. 67 W.	7.1	N. 88 W.	12.2	N. 22 W.	15.0	N. 72 W.	14.7
5,000								

Altitude m. s. l. (meters)	Ellendale, N. Dak. (444 meters)				Groesbeck, Tex. (141 meters)			
	Mean		Normal		Mean		Normal	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°	
Surface	N. 68 W.	3.5	N. 54 W.	3.4	W.	1.6	N. 68 W.	1.1
250					S. 83 W.	2.5	S. 85 W.	1.2
500	N. 67 W.	4.1	N. 58 W.	3.9	S. 88 W.	3.2	S. 60 W.	2.4
750	N. 59 W.	5.9	N. 57 W.	5.9	S. 89 W.	3.8	S. 62 W.	3.4
1,100	N. 54 W.	7.0	N. 56 W.	6.6	W.	4.4	S. 62 W.	4.5
1,250	N. 56 W.	7.6	N. 57 W.	7.4	W.	4.9	S. 68 W.	5.6
1,500	N. 58 W.	9.2	N. 57 W.	8.2	N. 87 W.	5.3	S. 70 W.	6.4
2,000	N. 61 W.	10.0	N. 59 W.	9.8	S. 85 W.	6.5	S. 75 W.	7.8
2,500	N. 60 W.	11.6	N. 62 W.	11.7	N. 79 W.	8.5	S. 78 W.	9.5
3,000	N. 65 W.	13.0	N. 65 W.	13.0	N. 74 W.	9.4	S. 81 W.	11.0
3,500	N. 68 W.	15.0	N. 71 W.	14.9	N. 63 W.	10.5	S. 84 W.	11.7
4,000	N. 28 W.	13.7	N. 69 W.	13.8	N. 66 W.	13.8	S. 86 W.	12.0
4,500	N. 32 W.	14.9	N. 83 W.	14.1	N. 67 W.	18.1	N. 82 W.	12.5
5,000								

Altitude m. s. l. (meters)	Royal Center, Ind. (225 meters)				Washington, D. C. (34 meters)			
	Mean		Normal		Mean		Normal	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°	
Surface	S. 34 W.	2.4	S. 54 W.	2.4	N. 51 W.	1.1	N. 44 W.	1.4
250	S. 32 W.	2.7	S. 53 W.	2.6	N. 64 W.	3.3	N. 62 W.	3.6
500	S. 37 W.	5.3	S. 58 W.	5.4	N. 71 W.	5.3	N. 67 W.	5.9
750	S. 50 W.	6.4	S. 67 W.	7.0	N. 60 W.	6.1	N. 68 W.	7.4
1,100	S. 63 W.	6.4	S. 77 W.	8.1	N. 63 W.	7.1	N. 68 W.	8.0
1,250	S. 69 W.	6.4	S. 82 W.	9.5				
1,500	S. 70 W.	7.3	S. 87 W.	10.6	N. 63 W.	7.8	N. 68 W.	10.7
2,000	S. 75 W.	9.2	N. 88 W.	12.2	N. 63 W.	10.6	N. 70 W.	12.5
2,500	S. 83 W.	9.6	N. 86 W.	13.8	N. 78 W.	11.6	N. 75 W.	14.9
3,000	W.	8.8	N. 88 W.	13.6	N. 83 W.	12.9	N. 76 W.	16.1
3,500	S. 75 W.	11.5	N. 88 W.	12.8	S. 86 W.	11.1	N. 70 W.	18.8
4,000	S. 72 W.	12.6	S. 71 W.	11.9	S. 77 W.	14.0	N. 79 W.	17.3
4,500	S.	14.0	S. 76 W.	9.7	S. 75 W.	13.2	N. 76 W.	19.6
5,000					S. 68 W.	20.0	N. 72 W.	18.6

AEROLOGICAL OBSERVATIONS FOR THE YEAR 1928

By L. T. SAMUELS

The most striking feature of Table 1 is the preponderance of negative departures for all elements, viz, temperature, relative humidity, and vapor pressure. As is usually the case with yearly departures, they are of relatively small magnitude.

Free-air resultant wind directions were northerly instead of southerly at Due West and Groesbeck in February, at Due West and Royal Center in March, at Ellendale in May and September, at Groesbeck in September, and at Due West in December.

A marked lack of southerly component occurred at most stations in April and at Broken Arrow and Royal Center in September, an excess of northerly component at Washington in May, and a southerly instead of the normal northerly component at Due West in October.

The resultant velocities at practically all stations were considerably above normal in January; also at Washington and Ellendale in April, at Due West, Groesbeck, and Washington in June, at Ellendale in September, and at Groesbeck in October.

A total of 1,505 kite flights were made during the year at the five aerological stations and the average altitude was 2,693 meters above sea level. The highest flight of the year (6,000 meters) was made at Royal Center, Ind., on April 18.

One hundred and seventy-one airplane observations were made at the naval air station, Anacostia, D. C.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during the year of 1928*

TEMPERATURE (°C.)

Altitude m. s. l. (meters)	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center, Ind. (225 meters)		Washington, D. C. (7 meters)*	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Surface	15.1	−0.4	15.4	−1.4	6.1	+0.5	16.9	−1.2	10.2	−0.8	15.0	+1.8
250	15.0	−0.4	15.2	−1.3			16.5	−1.0	10.0	−0.8	13.0	+1.1
500	13.9	−0.2	13.9	−0.9	5.9	+0.4	15.5	−0.8	8.4	−0.6	11.6	+0.7
750	12.9	−0.2	13.0	−0.6	5.4	+0.4	14.6	−0.8	7.2	−0.6	10.3	+0.5
1,000	12.1	−0.2	11.9	−0.6	4.7	+0.1	14.0	−0.7	6.1	−0.7	8.9	+0.3
1,250	11.3	−0.1	10.7	−0.6	3.8	−0.2	13.4	−0.5	5.1	−0.7	7.5	+0.1
1,500	10.4	−0.1	9.5	−0.6	2.8	−0.4	12.6	−0.4	4.0	−0.8	6.1	−0.2
2,000	8.3	0.0	7.2	−0.5	0.4	−0.6	10.3	−0.6	1.8	−0.9	3.8	−0.5
2,500	5.8	+0.1	4.8	−0.5	−2.3	−0.7	7.7	−0.8	−0.5	−0.9	1.6	−0.5
3,000	3.0	+0.1	2.3	−0.5	−5.1	−0.7	4.9	−1.0	−2.7	−0.6	−0.9	−0.5
3,500	0.4	+0.3	−0.2	−0.3	−7.9	−0.7	1.9	−1.3	−5.3	−0.6	−3.9	−0.6
4,000	−2.3	+0.5	−2.9	−0.2	−10.5	−0.5	−1.0	−1.4	−7.9	−0.6		
4,500	−5.3	+0.3	−6.1	−0.6	−13.1	−0.2	−3.8	−1.5	−10.7	−0.6		
5,000	−7.7	+0.7	−8.5	−0.3	−17.3	−1.6	−5.2	−0.1	−13.5	−0.2		

TABLE 1.—*Free-air temperature, relative humidities, and vapor pressures during the year of 1928*—Continued

RELATIVE HUMIDITY (%)

Altitude m. s. l. (meters)	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center, Ind. (225 meters)		Washington, D. C. (7 meters)*	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Surface	68	0	70	+4	67	−5	75	+1	71	+1	63	−6
250	68	0	70	+4			74	+1	70	0	63	−5
500	65	0	67	+2	66	−5	71	0	68	−1	61	−5
750	63	0	64	0	61	−6	66	−2	67	−1	59	−5
1,000	61	0	63	−1	58	−6	59	−4	65	−1	59	−4
1,250	58	−1	62	−2	56	−5	53	−6	62	−2	58	−5
1,500	56	−1	61	−2	54	−5	49	−6	60	−2	58	−5
2,000	52	−1	58	−2	50	−7	44	−5	54	−4	56	−5
2,500	49	−1	56	−1	49	−7	39	−6	50	−4	52	−5
3,000	47	−2	51	−3	48	−7	36	−6	45	−7	48	−6
3,500	44	−4	47	−5	46	−8	36	−4	43	−7	49	−3
4,000	41	−5	47	−4	41	−12	34	−5	44	−4		
4,500	35	−9	47	−4	39	−13	31	−6	45	−3		
5,000	24	−19	29	−17	51	+1	27	−10	43	−4		

VAPOR PRESSURE (*mb.*)

Altitude m. s. l. (meters)	Broken Arrow Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure	Washington Mean	Departure
Surface	13.61	−0.15	14.04	+0.04	7.67	−0.40	16.15	−0.63	10.52	−0.26	12.87	+0.37
250	13.48	−0.17	13.81	+0.02			15.58	−0.58	10.37	−0.26	11.40	+0.04
500	12.04	−0.12	12.35	−0.02	7.43	−0.43	14.10	−0.57	9.15	−0.21	9.99	−0.22
750	10.82	−0.13	11.18	−0.15	6.51	−0.50	12.30	−0.86	8.27	−0.23	8.87	−0.38
1,000	9.75	−0.22	10.20	−0.25	5.87	−0.51	10.53	−1.07	7.47	−0.28	8.00	−0.46
1,250	8.75	−0.25	9.21	−0.35	5.33	−0.49	9.08	−1.14	6.67	−0.33	7.33	−0.43
1,500	7.88	−0.17	8.27	−0.37	4.79	−0.48	7.89	−1.09	5.90	−0.37	6.63	−0.51
2,000	6.20	−0.14	6.61	−0.27	3.75	−0.56	6.04	−0.89	4.51	−0.51	5.35	−0.53
2,500	4.88	−0.08	5.30	−0.13	3.00	−0.53	4.47	−1.01	3.48	−0.38	4.19	−0.43
3,000	3.89	−0.04	4.18	−0.13	2.39	−0.45	3.46	−0.92	2.62	−0.41	2.93	−0.58
3,500	2.99	−0.16	3.37	−0.10	1.84	−0.44	2.88	−0.66	2.09	−0.29	2.52	−0.13
4,000	2.35	−0.10	2.84	+0.02	1.33	−0.50	2.31	−0.57	1.74	−0.10		
4,500	1.61	−0.30	2.23	−0.14	1.03	−0.45	1.91	−0.43	1.56	+0.02		
5,000	1.03	−0.50	1.41	−0.39	0.90	−0.28	1.51	−0.56	1.28	−0.03		

* Naval air station.

THE WEATHER IN THE UNITED STATES

THE WEATHER ELEMENTS

By P. C. DAY

GENERAL CONDITIONS

December, 1928, was notable for the wide extent of the precipitation shortage, the few days with extensive precipitation either rain or snow, and the preponderance of days having weather favorable for outdoor occupations.

PRESSURE AND WINDS

The month opened with cloudy weather and local rains over the Atlantic and Gulf coasts and similar conditions prevailed in the far Northwest, with a low-pressure area developing over the upper Missouri Valley. This low-pressure area advanced southeastward to the Dakotas by the morning of the 2d, attended by light snow over the northern plains and the near-by Canadian Provinces, and extended during the following 24 hours to the vicinity of Lake Michigan with increased intensity, the precipitation area being still confined to the immediate vicinity of the storm center. The storm diminished rapidly after crossing the Lakes and apparently dissipated during the following day in the region to northward of Lake Superior though light snow extended eastward to New York and New England. By the following day,

however, the precipitation area in the northeast had extended southward and in connection with a storm area moving eastward from the southern plains, light rain or snow had overspread an extensive area from the middle Mississippi Valley and Great Lakes eastward except along the south Atlantic coast.

Save for scattered light precipitation in the far West during the first decade, no important cyclonic disturbances crossed the country during that period save as previously indicated.

Beginning early in the first decade, high atmospheric pressure developed over the Plateau region and mostly clear weather prevailed over that region and later to the eastward, until about the 12th, at which time a cyclone of moderate proportions overspread the southern Plateau and Rocky Mountains and moved to eastern Oklahoma and western Arkansas by the morning of the 13th, attended by local heavy rains in portions of the west Gulf States. During the 14th the rain area extended northward to the Lake Michigan area and eastward nearly to the middle and south Atlantic coasts, but was largely dissipated by the morning of the 15th, though some local heavy rains occurred within the 24-hour period near the middle Atlantic coast. Closely following the track of the storm referred to above, another low-pressure area had moved to the southern plains by the morning of the 16th, attended by local precipitation near its path, and by the morning of the 17th it was central over Indiana. Precipitation had covered an extensive area from the southern plains northeastward to beyond Lake Superior, light snow occurring over wide areas from the Missouri Valley northeastward to the upper Lakes, with local heavy rains in protions of the lower Ohio and middle Mississippi Valleys. By the following day the storm center had advanced to the lower St. Lawrence Valley and precipitation had extended to all sections from the Mississippi River eastward save extreme southern Florida, but the falls were mostly light.

Prior to the passage of the cyclone referred to above, high-pressure had again become established in the Plateau region and dominated the weather over that and near-by areas, extending later into most eastern districts during the remainder of the month, some local precipitation occurring during the period along the Pacific coast, but fair weather prevailed in most central and eastern districts.

The average sea-level pressure of the month was above normal in all districts save in Minnesota and small portions of near-by States, the excesses being comparatively large in practically all western regions, but the values diminishing in all directions from the Plateau. Compared with the preceding November pressure was higher in all districts save from the Dakotas and eastern Montana southeastward to the middle and east Gulf coasts.

Due to the general high pressure existing there were few important cyclones, and winds of importance were infrequent though small tornadoes occurred at several points in Texas on the 12th.

The general pressure distribution and prevailing winds are shown on the usual charts, and the main facts as to storm damage appear as usual in the table at the end of this section.

TEMPERATURE

The first half of the month showed no marked abnormalities in the temperature distribution, though the week ending the 18th was mainly much warmer than normal over the districts east of the Rocky Mountains and moderately cool to the westward.

The week ending the 25th continued warm over the eastern slope of the Rocky Mountains and from the middle Plains northward and into the western Canadian Provinces, but moderately cool over most other districts except distinctly cold over the Plateau region.

The final week of the year was warmer in all districts save over southern Florida, and the week as a whole was distinctly warm over most northern districts.

For the month as a whole the temperature averages were above normal over all parts of the United States, and Canada as well, from the Rocky Mountains eastward save near the Gulf and south Atlantic coasts where they were normal or slightly below. The averages were decidedly above normal from the upper Missouri Valley eastward and over the adjacent Canadian Provinces, Some portions of the northern Plains and upper Mississippi Valley States having averages among the highest of record for December.

The monthly means were below normal in all districts from the Rocky Mountains westward, but the departures were mainly small.

The warmest periods were the 3d to 4th over the Southeastern States, the 7th to 14th in the upper Mississippi Valley, Lake region, and portions of near-by areas, and 27th to 28th in the Ohio Valley and thence to the Rocky Mountains and over the districts to westward.

The minimum temperatures were fairly well scattered through the month, ranging from the 3d to 23d. The lowest reported was 41° below zero at a point in Montana.

PRECIPITATION

The precipitation as a whole was unusually light, only six States, all located in the southern Plains and middle Mississippi Valley, having monthly amounts for the State in excess of the normal.

The deficiencies were rather large in the Atlantic coast and east Gulf States, where in several instances the monthly totals were the least of record for 50 years or more, Burlington, Vt., reporting the month as the driest December in the past 100 years.

In areas where the precipitation was above the normal the excesses were mainly small, so that the total precipitation for the month as a whole, considering all parts of the country, was probably the least of record for December.

SNOWFALL

December was markedly deficient in snowfall over the greater part of the country. East of the Rocky Mountains the ground was bare or had only a light covering during any material part of the month, and at the end only slight depths had accumulated on the ground in the more northern districts.

In the mountain regions of the West fairly good depths had accumulated by the end of the month in portions of the Rocky Mountain region, and in some of the mountains of the Northwest, but in the high elevations of California and the Southwest the amounts of stored snow were mainly much less than normal.

RELATIVE HUMIDITY

Owing to the general absence of precipitation and to the prevalence of mainly higher than the normal temperatures, relative humidity was largely less than normal in practically all parts of the country, though this was not the case in some portions of the Rocky Mountain and Plateau regions, where important excesses in the percentages were noted.

SEVERE LOCAL STORMS, DECEMBER, 1928

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Salisbury to Princess Anne, Md.	8					High winds	Poles blown down; telephone service impaired	Official, U. S. Weather Bureau.
Pearland, Tex. (near)	12	5:15 p. m.	20		$10,000	Tornado	Buildings damaged; 1 person injured	Do.
Zavalla, Tex. (near)	12	5:30 p. m.	100	1		do	Everything in 1-mile path destroyed or damaged; 5 persons injured.	Do.
Center (near) to Tenaha (near), Tex.	12	6 p. m.	50	1	3,000	do	A number of buildings destroyed; timber lands damaged; 3 persons injured.	Do.
Nobile to Benson, La.	12	6 p. m.	200	1	[1] 16,700	do	Buildings and timber damaged; livestock killed; path 12 miles; a few persons injured.	Do.
Sabine and De Soto Parishes, La.	12					High winds	Timber and other property damaged	Do.

[1] Includes damage in Sabine and De Soto Parishes, La., by winds not tornadic (item following).

RIVERS AND FLOODS

By R. E. SPENCER

Rains from December 11 to 13 and again, in heavier falls, on December 16 and 17 over the area from Arkansas and eastern Oklahoma southward to Texas and the Gulf of Mexico resulted in moderate floods in the Ouachita and lower Black Rivers of Arkansas, and in the Sulphur and Trinity Rivers of Texas.

No direct losses were reported except in the Sulphur River section of Texas, where the total, largely in bridges, highways, levees, etc., amounted to $46,000. Property worth $140,000 was saved in this section through Weather Bureau warnings. On the Ouachita such advantage was taken of the flood warnings that no avoidable loss occurred; though damage done to winter pastures was considerable. The Trinity River rise was forecast accurately and well in advance, with resultant losses negligible and $7,000 saved in livestock and movable property.

[Dates in December except as otherwise specified]

River and station	Flood stage	Above flood stages—dates From—	Above flood stages—dates To—	Crest Stage	Crest Date
MISSISSIPPI DRAINAGE					
Illinois:	*Feet*			*Feet*	
Peru, Ill.	14	(1)	3	15.9	Nov. 20.
		15	(2)	17.1	19.
Henry, Ill.	10	19	27	10.6	21–22.
Havana, Ill.	14	21	(2)	14.7	26.
Beardstown, Ill.	14	23	(2)	14.8	27–28.
St. Francis: St. Francis, Ark.	17	3	10	18.6	8.
		17	29	21.0	24.
Petit Jean: Danville, Ark.	20	18	19	20.6	19.
Black:					
Corning, Ark.	11	1	12	12.2	4–7.
		18	26	13.0	21.
Black Rock, Ark.	14	17	22	16.2	19.
Cache: Patterson, Ark.	9	20	30	9.6	23–25.
Sulphur:					
Ringo Crossing, Tex.	20	17	22	29.0	18.
Finley, Tex.	24	19	26	30.3	21.
Cypress: Jefferson, Tex.	18	20	26	24.2	21.
Ouachita:					
Arkadelphia, Ark.	12	17	19	19.7	18.
Camden, Ark.	30	20	25	34.9	22.
WEST GULF DRAINAGE					
Trinity:					
Dallas, Tex.	25	17	20	37.6	18.
Trinidad, Tex.	28	20	28	38.4	24.
Trinity, Elm Fork: Carrollton, Tex.	7	17	17	7.3	17.

[1] Continued from last month. [2] Continued at end of month.

MEAN LAKE LEVELS DURING DECEMBER, 1928

By UNITED STATES LAKE SURVEY

[Detroit, Mich., January 4, 1929]

The following data are reported in the Notice to Mariners of the above date:

Data	Lakes [1] Superior	Michigan and Huron	Erie	Ontario
Mean level during December, 1928:	*Feet*	*Feet*	*Feet*	*Feet*
Above mean sea level at New York	603.00	580.63	571.74	245.80
Above or below—				
Mean stage of November, 1928	−0.39	+0.02	+0.01	+0.13
Mean stage of December, 1927	+0.68	+1.85	+0.13	+0.15
Average stage for December, last 10 years	+1.12	+1.45	+0.31	+0.68
Highest recorded December stage	−0.13	−1.95	−1.79	−1.81
Lowest recorded December stage	+2.75	+3.09	+1.35	+2.37
Average departure (since 1860) of the December level from the November level	−0.27	−0.22	−0.07	−0.07

[1] Lake St. Clair's level: In December, 1928, 574.98 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, DECEMBER, 1928

By J. B. KINCER

General summary.—During the first decade rains were beneficial in the Pacific Coast States and higher temperatures in the far Northwest were helpful, but much range land in the central Rocky Mountain district was snow-covered, necessitating considerable feeding of livestock. East of the Rocky Mountains the ground was generally bare of snow, except in some north-central districts. The persistently cold weather, with continued soft fields from previous rains, was rather unfavorable for outside operations in parts of the interior and the freezing temperatures in the Southeast killed tender truck as far south as parts of central Florida and did some local damage to citrus. Precipitation was still needed in some south Atlantic and Gulf sections, but elsewhere soil moisture was largely sufficient.

During the second decade frequent rains in many places, heavy in the Mississippi Valley States and parts of the Southwest, caused farm operations to be largely suspended, but elsewhere seasonal work made good advance and was generally up to an average year. Showers

were helpful in the South Atlantic and east Gulf States and in the west Gulf area and far Southwest weather conditions were mostly favorable, with mild temperatures and absence of storms permitting free grazing of livestock in the northern plains. West of the Rocky Mountains cold weather, and in some places snow, was rather hard on livestock, but the additional moisture was of benefit to desert ranges. No materially harmful temperatures occurred, though frost was general in California, necessitating some heating of citrus groves.

During the last decade weather conditions were generally favorable for agricultural interests, as there was an absence of stormy weather until near the close of the month, and most of the period was mild and sunny. Conditions favored livestock in the northern Great Plains with much ranging possible and the higher temperatures in the Southwest were likewise favorable. Rainfall was again deficient in the Southern States, especially on the Florida uplands, where it was very dry. There was no material harm from low temperatures, except that the interior of southern Florida had harmful frosts on the 29th. Snowfall was beneficial for winter grains in parts of the interior of the Northwest and in the main winter wheat belt a snow cover that was deposited about the close of the month furnished protection from the cold wave that overspread the interior of the country immediately thereafter. Husking and housing the remaining corn crop made mostly good progress and conditions favored scrapping the outstanding cotton.

Small grains.—The growth of winter wheat and other fall-sown grains was checked by the cold weather during the first decade that prevailed from the Mississippi Valley eastward and but little growth was made in the more western portions of the belt. The main wheat sections were generally bare of snow, but wheat apparently suffered little or no harm from the low temperatures. In the Pacific Northwest warmer weather, with showers, was favorable toward the close of the period and in the more eastern States winter grains continued in favorable condition, except that moisture was needed in parts of the south Atlantic area.

During the second decade winter wheat and other fall-sown grains made some growth under the influence of the abnormally warm weather and abundant moisture in the central and eastern portions of the belt. Aside from the extreme western districts, the ground over the major wheat-producing areas was practically bare of snow; in the Rocky Mountain States and eastern Great Basin wheat fields were mostly snow-covered, while in Montana there were beneficial amounts over most wheat districts. In the Pacific Northwest conditions were less satisfactory, but the weather favored winter grain crops in the Atlantic States and the South.

The winter wheat belt continued generally bare of snow until about the close of the last decade, but the prevailing temperatures were not materially harmful, although there were complaints of thawing and freezing locally in the Ohio Valley. In the western belt conditions continued favorable and at the close of the period there was rather widespread snow in many central and western districts. Precipitation in the Pacific Northwest was helpful for winter grains, but additional moisture was needed. In the Rocky Mountain States wheat continued mostly satisfactory, but rainfall would have been beneficial in the South; conditions were generally favorable in the middle Atlantic area.

Miscellaneous crops.—Pastures continued in poor condition in central Gulf sections, but the absence of snow cover in most northern parts from the Great Plains eastward was not serious, as no injury to meadows was reported. Livestock were able to range freely in the northern Plains area throughout the month, with a consequent saving of feed, and much range remained open in the Rocky Mountain region. Conditions continued mostly favorable in the Southwest, but heavy feeding was necessary in the Great Basin, due mostly to poor pasturage. Livestock held up well with only few losses and slight shrinkage reported.

Winter truck did well in most sections where grown, except that some frost injury occurred in Florida and adjacent sections during the first and last decades. Conditions were favorable for grinding sugar cane in Louisiana and generally excellent progress was made. There was some local frost damage to citrus in Florida during the first decade and some dropping due to dryness was reported toward the close of the month, but this crop did well generally. Some firing was necessary in citrus groves in California, but no injury occurred and development of the crop was mostly satisfactory.

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

NORTH ATLANTIC OCEAN

By F. A. YOUNG

The weather over the North Atlantic during December presented few unusual features, with the possible exception of the very severe norther in the vicinity of Vera Cruz, Mexico, that will be referred to later. The number of days with gales was slightly below normal over the middle and eastern sections of the steamer lanes, and somewhat above west of the fiftieth meridian. Up to time of writing, no winds of hurricane force have been reported, although a few vessels encountered gales of force 11, as shown in table of gales and storms.

Judging from reports received, the number of days with fog was considerably below normal over the entire ocean, with the exception of the eastern part of the Gulf of Mexico, where it was observed on four days.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m. (seventy-fifth meridian), North Atlantic Ocean, December, 1928*

Stations	Average pressure	Departure [1]	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.53	(2)	30.36	6th	28.66	31st.
Belle Isle, Newfoundland	29.77	+0.07	30.50	5th	28.62	31st.
Halifax, Nova Scotia	30.00	+0.02	30.50	23d	29.12	29th.
Nantucket	30.08	−0.02	30.46	13th	29.32	18th.
Hatteras	30.12	−0.02	30.44	12th	29.72	18th.
Key West	30.10	+0.01	30.22	24th [3]	30.00	1st.[3]
New Orleans	30.16	+0.04	30.40	9th	29.90	17th.
Cape Gracias, Nicaragua	29.92	−0.06	29.98	27th [3]	29.84	23d.
Turks Island	30.10	+0.07	30.16	30th	30.02	9th.
Bermuda	30.20	+0.05	30.46	31st	29.90	28th.
Horta, Azores	30.29	+0.18	30.62	8th	29.88	16th.
Lerwick, Shetland Islands	29.82	+0.10	30.28	15th	29.24	10th.
Valencia, Ireland	29.99	+0.05	30.55	1st	28.94	10th.
London	30.02	+0.03	30.53	18th	29.14	30th.

[1] From normals shown on Hydrographic Office Pilot Chart, based on observations at Greenwich mean noon, or 7 a. m., seventy-fifth meridian time.
[2] No normal available. [3] And on other dates.

On the 2d Belle Isle was near the center of a disturbance, and gales of force 7 to 10 occurred between the east coast of Newfoundland and the forty-fifth meridian.

From the 3d to 6th moderate weather with comparatively high pressure prevailed over the greater part of the ocean, although on the 4th moderate westerly gales were encountered in a limited area over the western section of the steamer lanes, and on the 6th a number of land stations in the British Isles reported northerly to northwesterly winds of force 7.

On the 7th one moderate disturbance was central near 41° N., 47° W., and another in the North Sea, while southerly winds of force 9, accompanied by high barometric readings, were reported near 50° N., 57° W.

Charts VIII to XI show the conditions from the 8th to 11th, when both the eastern and western sections of the ocean were swept by storms that reached their maximum intensity and extent on the 10th.

From the 12th to 17th, moderate weather was the rule over the greater part of the ocean, although on the 15th a disturbance was central near 43° N., 47° W., with southerly winds of force 9 to 10 between the fiftieth and sixtieth meridians. On the same day a southerly wind of force 10 was reported about 500 miles west of Scotland.

On the 18th a moderate gale prevailed off Hatteras, and on the same day an exceptionally severe "norther" was reported by the land station at Vera Cruz, Mexico, the wind being given as north, 72 miles an hour, barometer 29.94 inches. This must have been of very limited extent, as the station at Tampico reported wind north-northwest, force 1, while no ships' reports have been received denoting any unusual conditions in that vicinity.

On the 20th moderate conditions again prevailed, except for a comparatively slight disturbance central in the Gulf of Mexico. This moved rapidly northeastward, and on the 21st was central near Sable Island, with moderate southerly gales in the easterly quadrants.

On the 22d westerly gales occurred on the steamer lanes between the fortieth and sixtieth meridians, and on the 23d between the twentieth and fortieth. On the 23d there was also a well developed LOW off Hatteras that moved eastward, and on the 24th was central near 39° N., 54° W.

On the 25th the steamer lanes east of the twenty-fifth meridian were again swept by moderate to strong westerly gales, the storm area extending nearly to the Azores, while on that date and on the 26th storm reports were also received from vessels in widely scattered sections of the ocean.

On the 27th a LOW, central near 50° N., 35° W., was accompanied by moderate gales, with rain, hail, and snow over a limited area in the westerly quadrants. This LOW moved eastward, and on the 28th the center was near 53° N., 27° W., the weather conditions remaining about the same as on the preceding day; by the 29th the center was near the west coast of Ireland, and the storm area extended as far west as the thirtieth meridian.

On the 27th there was also a disturbance about 300 miles northeast of the Bermudas that moved slowly northward, and by the 29th reached the Gulf of St. Lawrence. This LOW moved but little in the next three days, and during the remainder of the month moderate to strong westerly gales swept the American coast as far south as the thirty-fifth parallel, and on the 31st heavy weather also occurred over the area from the fortieth to fiftieth parallels, and the fortieth to forty-fifth meridians.

OCEAN GALE AND STORM REPORTS

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH PACIFIC OCEAN			° ′	° ′				Inches					
Pres. Jefferson, Am. S. S.	Yokohama	Honolulu	33 40 N.	155 00 W.	Nov. 30.	8 p., 30	Dec. 1	28.95	SE	NNW., 8	NNW	NNW., 10	SSW.-NNW.
Toba Maru, Jap. S. S.	do	San Francisco	41 00 N.	168 17 W.	30	1 a., 1	1	28.58	S	SW., 10	WSW	SW., 10	4 pts.
Illingworth, Br. S. S.	Panama	Yokohama	28 10 N.	160 00 E.	30	7 p., 30	1	29.39	S	W., 11	NW	W., 11	SW.-W.
Rakuyo Maru, Jap. S. S.	Yokohama	Honolulu	32 04 N.	168 25 E.	30	5 a., 1	1	28.99	SSW	W., 9	NNW	NW., 11	SW.-W.-NW.
Broad Arrow, Am. S. S.	San Pedro	Shanghai	32 00 N.	176 52 E.	Dec. 1	1 p., 1	1	29.06	SSW	SSW., 10	NW	NW., 12	SSW.-NW.
Akibasan Maru, Jap. S. S.	Yokohama	San Francisco	47 45 N.	170 30 W.	1	4 a., 2	2	28.83	SE	WSW., 10	SW	WSW., 10	10 pts.
Oregon, Am. S. S.	Hakodate	do	44 02 N.	148 50 E.	3	6 p., 4	5	29.31	SE	WSW., 5	WSW	ESE., 10	WSW.-SW.
Hayo Maru, Jap. S. S.	Muroran	Vancouver	43 03 N.	158 35 E.	4	6 p., 4	4	29.30	SSE	S., 10	SSW	S., 10	SSE.-SSW.
Ixion, Br. S. S.	Yokohama	Victoria	49 30 N.	165 00 W.	5	Noon, 5	6	28.72	SSE	SW., 7	W	W., 11	SW.-WSW.
Pres. Jackson, Am. S. S.	Victoria	Yokohama	51 55 N.	168 28 W.	5	1 a., 6	7	28.20	S	W., 8	WNW	W., 11	4 pts.
Kentucky, Am. S. S.	Otaru	San Francisco	48 48 N.	151 50 W.	6	8 a., 6	9	28.86	SSE	WSW., 9	WSW	SSW., 10	SSE.-WSW.
Fukuyo Maru, Jap. S. S.	Japan	Portland	48 17 N.	162 17 W.	8	Noon, 8	8	29.03	WSW	W., 11	W	W., 12	
Hanley, Am. S. S.	Balboa	Los Angeles	14 11 N.	94 45 W.	8	6 p., 8	9	29.90	NNW	NNW., 8	N	—, 9	NNW.-N.
Olympia, Am. S. S.	Otaru	San Francisco	49 12 N.	158 16 W.	5	6 a., 6	10	28.82	W	SW., 5	SW	S., 10	S.-SW.-W.
Koyo Maru, Jap. S. S.	Muroran	Tacoma	50 00 N.	147 50 W.	6	4 p., 6	10	29.11	S	S., 7		SSE., 10	S.-SW.-SSE.
Haksuhika Maru, Jap. S. S.	Astoria	Yokohama	43 47 N.	153 11 E.	10	9 p., 10	12	28.76	E	SW., 6	NE	NNE., 11	E.-SW.-NW.
Golden Peak, Am. S. S.	Hong Kong	San Francisco	40 00 N.	163 25 E.	10	5 a., 11	13	29.44	SSE	S., 10	W	S., 10	SSE.-S.-SW.
Fukuyo Maru, Jap. S. S.	Japan	Portland	48 52 N.	151 32 W.	10	8 a., 10	12	28.74	ESE	NE., 2	NW	NW., 11	
City of Vancouver, Br. S. S.	Yokohama	San Francisco	44 30 N.	176 50 W.	11	8 a., 11	11	29.22	S	S., 10	SSW	S., 10	SSE.-S.
Oregon, Am. S. S.	Hakodate	do	48 53 N.	165 06 W.	11	2 a., 11	11	29.24	SSE	S., 5	S	SSE., 11	SSE.-S.
Pres. Jackson, Am. S. S.	Victoria	Yokohama	46 38 N.	159 56 E.	11	2 p., 11	12	28.48	NW	NW., 6	WNW	NW., 11	NW.-N.-NNW.
Blythmoor, Br. S. S.	Canal Zone	Vancouver	Off Victoria		11	4 a., 12	12	29.38	SSE	ESE., 7	ESE	E., 10	SE.-ESE.
Oridono Maru, Jap S. S.	Columbia River.	Yokohama	46 05 N.	161 30 E.	11	3 p., 11	12	28.44	NW	WSW., 5	NW	NW., 11	WNW.-NW.
Malama, Am. S. S.	Bellingham	Honolulu	47 10 N.	127 29 W.	11	—., 11	13	29.25	SE	SSE., —	NW	NW., 10	
Oregon, Am. S S.	Hakodate	San Francisco	48 10 N.	155 34 W.	13	8 a., 14	15	29.49	SW	SSE., —	S	SSE., 10	SSE.-SW.
Washington, Am. S. S.	Legaspi	do	44 16 N.	159 04 W.	14	6 a., 15	15	29.10	ESE	S., 10	SW	SSW., 11	S.-SSW.
Havre Maru, Jap. S. S.	Miike	Grays Harbor	49 23 N.	157 40 W.	15	4 a., 15	15	28.59	SE	S., 11	SW	S., 11	S.-SSW.
Talthybius, Br. S. S.	Victoria	Yokohama	51 40 N.	160 04 W.	15	4 p., 17	17	29.15	NE	NNE., —	NNE	S., 10	NNE.-N.
Tecumseh, Br. S. S.	Yokohama	San Pedro	40 40 N.	148 00 W.	16	4 a., 17	17	29.90	SSE	SSE., 9	SSE	SSE., 10	Steady.
Erviken, Nor. S. S.	Vancouver	Yokohama	46 20 N.	158 10 E.	17	Noon, 18	19	28.98	SW	W., —	NW	NW., 10	SW.-W.-NW.
Silveray, Br. M. S.	Soerabaya	San Francisco	14 20 N.	136 30 E.	17	4 p., 18	19	29.69	N	W., 7	W	W., 9	N.-NW.-W.
Shabonee, Br. S. S.	Shanghai	San Pedro	37 30 N.	165 00 E.	19	4 a., 20	20	29.35	S	SW., 9	NW	SW., 10	SW.-W.-NW.
Golden Peak, Am. S. S.	Hong Kong	San Francisco	43 35 N.	145 40 W.	20	Noon, 20	22	29.48	WSW	WSW., 7	WSW	WSW., 11	Steady.
Golden Mountain, Am. S. S.	Tsugaru Straits.	do	49 30 N.	154 06 W.	20	2 a., 21	23	28.53	SE	S., 10	SW	SE., 12	S.-WSW.
Hakubasan Maru, Jap. M. S.	Yokohama	do	44 25 N.	140 30 W.	21	6 a., 21	22	29.80	S	S., 7	SSE	S., 10	
Kaga Maru, Jap. S. S.	do	Victoria	50 33 N.	140 40 W.	23	8 a., 23	23	29.11	SSE	SSE. —	SSW	SSE., 10	7 pts.
Blythmoor, Br. S. S.	Vancouver	Panama	42 12 N.	124 56 W.	23	1 p., 24	24	29.60	S	S., 9	WSW	S., 9	S.-WSW.
Astral, Am. S. S.	Sydney	Honolulu	11 52 N.	166 28 W.	24	—., 24	27	29.98	ENE	ENE., —	NE	ENE., 9	Steady.
Steel Worker, Am. S. S.	San Pedro	Yokohama	33 27 N.	143 50 E.	25	10 a., 25	25	29.67	SW	NW., —	NW	NNE., 10	SW.-NW.-NNE.
West Nilus, Am. S. S.	Balboa	San Pedro	15 30 N.	94 22 W.	25	6 p., 25	26	29.94	N	N., 7	NE	NNE., 9	N.-NE.
Ryujin Maru, Jap. S. S.	Miike	Vancouver	46 00 N.	164 50 E.	25	7 a., 26	27	28.25	ENE	WNW., 5	W	WNW., 12	
Siberia Maru, Jap. S. S.	Yokohama	Honolulu	32 23 N.	171 33 E.	25	Noon, 26	27	29.81	ESE	SE., 11	SW	SE., 11	SE.-S.
Steel Traveler, Am. S. S.	New York	do	21 15 N.	151 50 W.	26	Mdt., 26	27	30.23	N	N., 7	E	NE., 9	N.-NE.
Tsuyama Maru, Jap. S. S.	Yokohama	San Francisco	44 30 N.	152 12 W.	27	2 p., 27	29	28.91	ESE	W., 8	W	N., 10	ESE.-W.
San Diego Maru, Jap. M. S.	do	San Pedro	35 12 N.	153 08 E.	29	2 a., 30	31	28.64	SW	NW., 10	WNW	NW., 10	SW.-W.-NNW.
Etna Maru, Jap. S. S.	Miike	Portland	46 35 N.	177 30 W.	30	1 p., 30	31	28.84	SE	SE., 10	SSW	SE., 10	SE.-S.-SSW.
Tamaha, Br. S. S.	Yokohama	San Francisco	38 10 N.	164 30 E.	30	Noon, 30	31	28.67	S	S., 8	WNW	W., 10	S.-SW.-W.
NORTH ATLANTIC OCEAN													
Blue Triangle, Am. S. S.	Lisbon	Philadelphia	38 00 N.	62 00 W.	Dec. 1	10 a, 1	Dec. 1	29.79	SW	SW., 10	NW	—, 10	SW.-W.-NW.
Edgehill, Am. S. S.	Galveston	Liverpool	35 00 N.	74 30 W.	7	3 p., 7	14		NE	NE., 7	NW	SW., 11	
Balsam, Am. S. S.	Avonmouth	Baltimore	50 27 N.	38 56 W.	7	8 p., 7	7	30.14	S	S., 9	S	S., 9	Steady.
Sagaporak, Am. S. S.	Gothenburg	Portland, Me.	58 10 N.	1 10 E.	6	4 a., 7	8	29.59	SW	NW., 9	Var	NW., 10	NW.-N.-SW.
Irma Schindler, Ger. S. S.	New Orleans	Falmouth	46 51 N.	9 49 W.	6	Mdt., 7	8	30.12	NE	N., 9	N	NNE., 10	Steady.
McKeesport, Am. S. S.	New York	Havre	39 40 N.	66 12 W.	8	10 p., 9	10	29.54	NE	SSE., 10	SW	—, 11	SSE.-SW.
Seattle Spirit, Am. S. S.	Norfolk	Bremen	49 20 N.	19 50 W.	9	3 p., 9	10	29.20	WNW	WNW	N	NW., 10	WNW.-N.
Coldbrook, Am. S. S.	Antwerp	New Orleans	44 00 N.	14 00 W.	9	6 p., 9	11	29.74	SW	SW	WNW	NW., 10	
Reliance, Ger. S. S.	Hamburg	New York	41 30 N.	64 12 W.	10	8 a., 10	10	29.45	S	SW		—, 11	
Stuttgart, Ger. S. S.	Cobh	Halifax	51 28 N.	22 19 W.	9	4 a., 10	10	29.24	WNW	NW., 11	NW	NW., 11	Steady.
Exton, Am. S. S.	Casa Blanca	New York	34 50 N.	7 00 W.	10	8 p., 10	10	29.67	SW	SW., 10	NW	SW., 10	W.-SW.-NW.
West Nosska, Am. S. S.	Norfolk	Liverpool	51 17 N.	9 46 W.	13	Noon, 13	14	29.66	SSE	SE., 10	SE	SE., 10	
McKeesport, Am. S. S.	New York	Havre	45 21 N.	41 36 W.	14	2 p., 14	14	29.69	N	NNW., 8	NNW	N., 9	N.-NNW.
Gaasterdijk, Du. S. S.	Rotterdam	New York	42 50 N.	54 58 W.	15	4 a., 15	15	29.50	WNW	NW., 7	N	NNW., 9	WNW.-N.
West Saginaw, Am. S. S.	New Orleans	Liverpool	47 45 N.	34 27 W.	16	Noon, 16	16	29.48	SSE	SSE., 10	SSE	SSE., 10	
Lord Antrim, Br. S. S.	Rotterdam	St. John, N. B	45 10 N.	54 00 W.	18	10 p., 18	19	29.67	S	S., 9	W	S., 9	S.-W.
Gulfking, Am. S. S.	Savannah	Port Arthur	27 40 N.	88 50 W.	20	8a., 20	20	29.85	N	N., 9	N	N., 10	W.-N.
Creole, Am. S. S.	New Orleans	New York	32 48 N.	77 40 W.	21	Mdt., 22	23	29.84	NW	N., 9	N	NE., 10	NW.-N.-NE.
New York City, Br. S. S.	Bristol	Philadelphia	49 35 N.	39 06 W.	21	8 a., 22	23	29.60	S	WSW., 8	W	W., 9	S.-WSW.
Yuri Maru, Jap. S. S.	Norfolk	Rotterdam	47 50 N.	25 05 W.	22	3 p., 23	23	29.98	SW	SW., 9	W	SW., 9	SW.-WSW.
West Harcuvar, Am. S. S	Boston	Hamburg	49 45 N.	20 30 W.	25	4 a., 25	25	29.75	SW	SW., 9	NW	W., 11	SW.-NW.
Bilderdijk, Du. S. S.	Rotterdam	Boston	46 51 N.	38 02 W.	26	11 p., 26	27	29.80	SSW	SW., 8	NW	SW., 9	SSW.-W.
City of Alton, Am. S. S.	do	New York	51 00 N.	24 20 W.	27	7 p., 27	29	29.52	SSW	SW., 9	W	—, 9	SW.-W.
River Orontes, Br. S. S.	Gibraltar	Boston	36 55 N.	65 00 W.	28	4 p., 28	30	29.60	W	W., 6	WSW	W., 10	W.-NW.-W.
Thuringia, Ger. S. S.	Cobh	New York	44 33 N.	55 44 W.	28	8 a., 29	31	29.15	ESE	SSW., 7	W	W., 10	SSE.-SSW.
City of Flint, Am. S. S.	Portland, Me.	London	50 26 N.	15 59 W.	29	4 a., 29	30	29.92	NW	NW., 7	NW	NW., 10	Steady.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

The average atmospheric pressure over the North Pacific Ocean during December, 1928, showed pronounced abnormalities. In the central region of the Aleutian cyclone, so far as indicated by the observations at Kodiak (29.29 inches) and Dutch Harbor (29.26 inches), the pressure was nearly a third of an inch below the normal, and at Dutch Harbor was the lowest for December in the record of the last 17 years. At Midway Island, on the contrary, the average of 30.17 inches, which was 0.13 inch above the normal, was next to the highest at that station since 1912. There was therefore an unusual barometric gradient between these two stations in middle longitudes, amounting to 0.91 inch. The greatest daily difference was on the 2d, with the Midway reading at 30.20 inches, and that of Dutch Harbor at 28.46 inches. The Aleutian cyclone was thus strongly developed, and with pressures below the normal for fully three-fourths of the month. The Pacific-California anticyclone was also well developed in central latitudes. with pressures slightly above the normal at all land stations within its boundaries.

Pressure data for several island and mainland coast stations in west longitudes are given in the following table:

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level at indicated hours, North Pacific Ocean, December, 1928*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Dutch Harbor [1]	29.26	−0.32	30.14	17th	28.34	6th.
St. Paul [1]	29.32	−0.29	30.02	26th	28.64	3d.[4]
Kodiak [1]	29.29	−0.29	30.26	17th	28.38	22d.
Midway Island [1]	30.17	+0.13	30.44	24th	29.96	30th.[4]
Honolulu [2]	30.08	+0.07	30.25	26th	29.92	31st.
Juneau [3]	29.77	−0.02	30.64	17th	28.84	8th.
Tatoosh Island [2 3]	30.04	+0.07	30.66	17th	29.16	24th.
San Francisco [2 3]	30.17	+0.06	30.47	30th	29.65	2d.
San Diego [2 3]	30.10	+0.06	30.26	20th	29.88	11th.

[1] P. m. observations only.
[2] A. m. and p. m. observations.
[3] Corrected to 24-hour mean.
[4] And on other dates.

The wind movement over much of the ocean showed an extraordinary activity, as a result largely of the abnormally great differences in pressure north and south, but partly because of intense storms issuing from upper latitudes of Asia. Gales were not only of daily occurrence over the ocean as a whole, especially north of the thirty-fifth parallel, but the number of days with gales of force 10 and upward was the greatest of any winter month in recent years. Also, according to reports already at hand, whole storm to hurricane velocities were encountered by vessels on the upper and middle routes on at least 11 days. Gales of forces 11 and 12 occasioned by traveling storms in east longitudes occurred on the 1st, 10th, 11th, 25th, and 26th; those occasioned by the Aleutian cyclone were reported as of the 5th, 6th, 8th, 11th, 15th, 20th, and 23d. The 11th was the day of most widespread severe storminess in northern waters. In some 5-degree squares between the fortieth and fifty-second parallels, where observations were thickest, there was upward of 25 to 30 or more per cent of the days with gales. Between 158° and 170° W., and closely along the fiftieth parallel, whole storm to hurricane winds were reported on five days during the early half of the month. A glance at the adjoining tabular reports of Gales and Storms will give a fair indication of the unwonted roughness of the weather during the closing month of the year.

Although there are no reports at hand at this writing of the existence of a typhoon in December, there are evidences of a depression of some activity west of Guam during the middle days of the month. The British motorship *Silveray* experienced a westerly gale of force 9 in this neighborhood in the 18th. A moderate gale occurred west of Luzon on the 17th.

On the 4th and 5th strong gales occurred between the Hawaiian Islands and Midway, and from the 24th to the 27th abnormally heavy northeast trades blew south and east of Hawaii, acquiring a force of 8 to 9 on the 25th to 27th as low in latitude as the thirteenth parallel. The Pacific-California anticyclone, extending farthest south during these days, gave highest pressure readings of the month at Honolulu.

The prevailing direction of the wind at Honolulu continued from the east, whence it blew 67 per cent of the time. The maximum velocity was at the rate of 42 miles an hour, from the northeast, during a thunderstorm on the 25th.

Moderate to strong northers, sometimes rising to force 9, covered the Gulf of Tehauntepec and a considerable southward stretch of the sea, on the 8th and 9th, and from the 24th to the 28th. On the 27th a norther of force 8 was experienced off the Costa Rican coast.

Little fog occurred over the traveled routes, except in local areas over the southern part of the Gulf of Alaska, and off the Washington and California coasts. From longitude 140° W., 48° to 51° N., eastward to Puget Sound, fog was quite general from the 14th or 15th to the 20th. Ten to 15 per cent of days with fog occurred off the middle and southern California coast. The phenomenon was observed on the 11th in the Gulf of Tehauntepec, and on the 30th a day's run northeast of Honolulu.

The following note on a singular electrical phenomenon was furnished by the British steamer *Collegian*, Capt. J. Jackson, San Francisco to Balboa, observers, D. Fraser, second officer, and G. Dewar, third officer:

Dec. 1, 3.50 a. m., lat. 11° 50′ N., long. 88° 45′ W. Lighting in low clouds, altitude about 10° to NNE. After one flash a streak of bluish light shot towards the zenith from the clouds, leaving a trail across the sky like a meteor to the altitude of about 30°, when it died out. The sky was clear except for clouds low on the horizon.

CLIMATOLOGICAL TABLES[1]

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, December, 1928

Section	Temperature		Monthly extremes						Precipitation		Greatest monthly		Least monthly	
	Section average	Departure from the normal	Station	Highest	Date	Station	Lowest	Date	Section average	Departure from the normal	Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	46.7	−0.6	2 stations	78	[2] 3	3 stations	15	[2] 8	2.16	−2.69	Seven Hills	7.03	Tuskegee	0.52
Arizona	43.5	−0.8	Nogales	84	27	2 stations	−14	[2] 16	0.75	−0.56	Prescott	2.65	2 stations	0.00
Arkansas	43.4	+0.9	Calico Rock	87	28	Dutton	10	20	4.41	+0.36	Grannis	8.34	Fort Smith	1.67
California	44.0	−2.1	2 stations	84	27	Helm Creek	−27	14	3.44	−0.73	Upper Mattole	13.00	Amos	0.00
Colorado	23.1	−1.9	Canon City	82	28	Hermit (near)	−31	[2] 17	0.40	−0.53	Garfield	2.91	11 stations	0.00
Florida	59.2	−0.5	Orlando	91	4	3 stations	22	[2] 9	1.45	−1.41	Cottage Hill	3.83	Jupiter	0.09
Georgia	48.4	+0.8	Albany	83	13	Blue Ridge	13	[2] 9	1.92	−2.34	Blakely	3.62	Clayton	0.70
Idaho	22.4	−3.1	2 stations	67	[2] 27	Obsidian	−28	4	1.59	−0.43	Roland	4.50	2 stations	0.16
Illinois	34.0	+3.5	Sparta	73	28	Marengo	−5	21	2.33	+0.09	Effingham	3.61	Galena	1.05
Indiana	34.6	+2.5	Rome	68	28	2 stations	−1	21	2.15	−0.75	Marengo	3.35	Plymouth	0.98
Iowa	28.7	+4.6	Sioux City	57	7	Perry	−15	5	0.89	−0.25	Wever	1.98	Akron	0.12
Kansas	35.8	+4.2	4 stations	76	27	Oberlin	−1	5	0.98	+0.04	Toronto	4.17	4 stations	0.00
Kentucky	39.5	+1.9	Calhoun	72	28	Farmers	5	22	2.32	−1.76	Bowling Green (No. 2).	5.13	Whitesburg	0.79
Louisiana	51.2	−1.1	2 stations	84	4	Tallulah	16	9	4.63	−0.62	Reserve	7.06	Tallulah	2.63
Maryland-Delaware	36.9	+1.8	3 stations	63	17	Oakland, Md	0	22	1.63	−1.66	Crisfield, Md	2.94	Frostburg, Md	0.83
Michigan	29.1	+4.2	Hillsdale	54	11	Humboldt	−14	6	1.59	−0.55	Paw Paw	3.94	Onaway	0.03
Minnesota	22.5	+7.8	Canby	56	12	Roseau	−32	21	0.62	−0.12	Cloquet	1.43	Beardsley	0.06
Mississippi	47.6	−0.5	4 stations	80	4	4 stations	14	9	3.19	−2.34	Pearlington	6.57	Yazoo City	0.68
Missouri	36.2	+2.3	2 stations	81	28	2 stations	0	5	2.24	+0.21	Morehouse	5.04	Maryville	0.23
Montana	23.8	+1.5	Billings	62	27	Outlook	−41	3	0.73	−0.17	Adel	3.30	Valentine	T.
Nebraska	29.1	+3.3	Sidney	74	28	Curtis	−11	8	0.16	−0.58	Mason City	1.00	8 stations	0.00
Nevada	28.7	−2.9	Searchlight	78	13	Beowawe	−21	19	0.54	−0.42	Kimberly	2.35	Millett	T.
New England	31.1	+4.5	Boston, Mass	61	18	Van Buren, Me	−23	23	2.49	−0.88	Machias, Me	5.01	Cornwall, Vt	0.04
New Jersey	36.3	+3.8	New Brunswick	63	18	2 stations	3	22	1.64	−2.29	Elizabeth	4.63	New Milford	0.69
New Mexico	33.0	−0.5	Tucumcari (No. 2)	82	28	Elizabethtown	−23	20	0.48	−0.32	Pesamonta	2.60	3 stations	0.00
New York	31.8	+5.2	2 stations	61	14	Stillwater	−16	22	1.33	−1.65	High Market	3.95	Elmira	0.04
North Carolina	42.7	+0.1	Lumberton	73	17	2 stations	9	[2] 9	2.53	−1.47	Hatteras	10.09	Marshall	0.35
North Dakota	20.7	+7.7	3 stations	57	[2] 9	Hansboro	−30	20	0.28	−0.26	Cooperstown	0.95	2 stations	0.00
Ohio	34.6	+3.4	Middleport	65	13	Summerfield	2	21	2.02	−0.90	Marietta (Best)	2.58	Cortland	0.83
Oklahoma	41.8	+2.5	Hollis	81	28	Boise City	3	18	2.05	+0.48	Idabel	6.48	Elk City	0.37
Oregon	33.1	−1.2	3 stations	66	[2] 9	Harper	−17	23	4.16	−0.25	Valsetz	16.85	2 stations	0.16
Pennsylvania	34.4	+3.3	Elk Lick	68	12	Brookville	−2	[2] 21	1.16	−2.07	Greensboro	2.57	Lawrenceville	0.28
South Carolina	46.1	−0.5	2 stations	78	[2] 4	3 stations	15	[2] 9	1.37	−1.65	Caesar's Head	5.14	Laurens	0.61
South Dakota	27.7	+7.7	Dowling	72	27	Ludlow	−15	4	0.17	−0.44	Hardy Ranger Station.	0.80	Academy	0.00
Tennessee	41.9	+1.4	Carthage	73	[2] 13	Waynesboro	11	9	1.92	−2.65	Tiptonville	4.34	Parksville	0.55
Texas	49.0	−0.8	Pierce	90	4	Dalhart	7	[2] 18	2.72	+0.56	Kaufman	8.32	5 stations	0.00
Utah	23.8	−2.7	2 stations	67	[2] 27	Lucien	−27	22	0.67	−0.56	Silver Lake	3.16	Hanskville	0.00
Virginia	38.8	+0.9	Onley	68	3	Mineral	7	10	1.69	−1.52	Diamond Springs	6.60	2 stations	0.55
Washington	31.6	−0.6	Olympia	64	23	Stockdill Ranch	−9	[2] 3	4.40	−1.16	Quinault	18.42	Alpowa Ranch	0.30
West Virginia	35.4	+2.0	Fairmont	70	13	Terra Alta	1	22	2.08	−1.35	Parsons	5.50	Perry	0.24
Wisconsin	24.9	+4.8	2 stations	55	[2] 7	5 stations	−25	21	1.05	−0.28	Milwaukee County Airport.	2.92	Mondovi	0.09
Wyoming	18.3	−2.1	Torrington	67	27	Riverside	−31	19	0.49	−0.33	Border	1.76	Elk Mountain	0.00
Alaska (November)	19.3	+5.6	2 stations	62	[1] 1	Allakaket	−50	24	3.48	+0.97	Cordova	30.14	White Mountain	0.09
Hawaii	69.9	0.0	Molokai Ranch	93	26	Volcano Observatory	47	27	8.79	−0.86	Papaikou (Mauka)	42.92	2 stations	0.00
Porto Rico	75.5	+1.0	Juncos	95	3	Jayuys	56	28	6.74	+2.01	San Cristobal	23.59	Juncos	1.35

[1] For description of tables and charts, see REVIEW, January, 1928, p. 29.

[2] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau Stations, December, 1928*

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	° F.	° F.	° F		° F	° F.		° F	° F	° F	° F	%	In.	In.		Miles								0–10	In.	In.
New England							34.7	+5.3										74	2.16	−1.2										5.5		
Eastport	76	67	85	29.90	29.98	0.00	31.6	+5.3	53	18	38	9	22	26	23	29	24	73	2.74	−1.0	13	8,877	w.	42	ne.	10	8	4	19	6.7	4.2	0.0
Greenville, Me.	1,070	6		28.80	30.01		24.0		47	18	31	−8	23	17	39				3.27		9		nw.			30	12	14	5		19.5	4.0
Portland, Me.	103	82	117	29.94	30.06	+.03	33.5	+5.9	51	16	40	10	22	27	30	29	24	71	3.55	−0.4	11	5,813	n.	26	w.	18	18	3	10	4.3	3.0	0.0
Concord	289	70	79	29.71	30.04	−.02	31.6	+4.8	59	17	40	4	23	23	37				1.61	−1.5	7	3,718	nw.	24	w.	30	15	6	10	5.0	T.	0.0
Burlington	403	11	48	29.60	30.06	+.01	30.2	+5.8	54	18	36	8	22	24	26				0.31	−1.6	6	7,164	s.	35	s.	19	3	6	22	7.9	1.7	0.0
Northfield	876	12	60		30.08	+.03	27.0	+6.6	54	18	35	4	23	19	37			82	1.15	−1.6	9	4,201	n.	23	se.	18	2	11	18	7.6	13.5	2.2
Boston	125	115	188	29.93	30.06	+.01	38.5	+6.0	61	18	45	17	22	32	27	34	29	72	2.61	−0.8	11	6,669	w.	28	w.	30	15	8	8	4.7	4.6	0.0
Nantucket	12	14	90	30.05	30.06	+.01	39.2	+3.4	54	18	44	21	22	34	20	36	32	80	3.61	0.0	12	10,345	w.	54	ne.	8	12	10	9	5.5	T.	0.0
Block Island	26	11	46	30.04	30.07	+.01	39.3	+3.3	56	17	44	21	22	34	18	36	31	74	2.85	−1.0	11	12,231	w.	48	w.	30	12	10	9	4.7	0.5	0.0
Providence	160	215	251	29.90	30.08	+.02	37.2	+5.6	58	18	44	16	22	30	24	32	27	69	2.87	−0.5	11	7,953	nw.	58	nw.	30	14	8	9	4.6	1.0	0.0
Hartford	159	122		29.93	30.11	+.04	36.5	+6.7	57	17	44	13	23	29	28				0.92	−3.0	8		sw.				16	5	10	4.4	0.4	0.0
New Haven	106	74	153	29.99	30.11	+.04	37.2	+4.7	56	17	44	16	22	30	25	32	26	68	1.60	−2.4	8	5,685	n.	28	s.	17	14	8	9	4.7	0.9	0.0
Middle Atlantic States							38.6	+3.1										72	1.34	−1.7										5.6		
Albany	97	107	115	30.00	30.11	+.03	34.2	+5.7	56	17	41	14	22	28	23	30	26	75	0.40	−0.2	6	4,275	sw.	26	s.	5	9	11	11	5.7	T.	0.0
Binghamton	871	10	84	29.13	30.09	.00	33.6	+5.4	57	18	40	11	22	27	28				0.16	−2.3	7	3,805	nw.	22	w.	18	7	6	18	6.9	0.6	T.
New York	314	414	454	29.78	30.13	+.04	39.4	+4.4	58	17	46	20	22	33	25	34	29	68	0.85	−2.8	7	10,799	nw.	48	sw.	18	10	10	11	5.7	2.3	0.0
Bellefonte	1,050	5	36	28.99	30.13		32.3		54	13	42	5	22	23	35	28	24	81	0.39		3		w.				10	9	12	5.9	T.	0.0
Harrisburg	374	94	104	29.75	30.17	+.05	37.0	+4.3	58	17	44	16	22	30	28	32	25	65	0.62	−2.0	3	3,915	w.	26	sw.	17	11	10	10	5.4	T.	0.0
Philadelphia	114	123	367	30.02	30.16	+.05	40.8	+4.5	60	17	47	21	22	34	25	36	30	68	1.50	−1.9	7	7,881	nw.	46	sw.	18	10	8	13	5.5	3.2	0.0
Reading	325	81	98	29.78	30.15		38.1		59	17	46	18	22	31	28	33	28	73	0.76	−2.6	7	3,923	w.	21	nw.	5	11	8	12	5.7	0.5	0.0
Scranton	805	111	119	29.24	30.14	+.04	35.2	+4.5	58	17	42	12	22	28	27	31	26	72	0.49	−2.1	7	4,427	sw.	28	nw.	30	6	7	18	7.0	0.4	0.0
Atlantic City	52	37	172	30.08	30.14	+.04	39.4	+3.0	56	1	46	21	22	33	22	35	31	77	2.03	−1.9	8	9,712	nw.	42	s.	17	14	6	11	4.7	3.9	0.0
Cape May	17	13	49				38.3	+0.3	57	1	46	18	22	31	23	35	32	82	2.25		10		nw.				14	7	10		9.6	0.0
Sandy Hook	22	10	55	30.10	30.12		38.8		58	17	44	22	22	34	22	35	31	76	1.07		9	9,793	w.	41	n.	8	11	9	11	5.1	2.4	0.0
Trenton	190	159	183	29.92	30.13		38.2		60	17	46	17	22	31	26	33	28	73	1.19	−2.0	8	6,146	nw.	34	nw.	18	11	7	13	5.6	1.7	0.0
Baltimore	123	100	113	30.02	30.15	+.02	41.0	+3.8	63	17	48	22	22	34	27	35	29	67	1.22	−2.2	7	5,587	sw.	36	w.	18	14	8	9	4.7	0.3	0.0
Washington	112	62	85	30.04	30.17	+.04	39.2	+2.6	62	17	48	20	22	30	30	33	28	70	1.21	−2.1	3	3,591	nw.	32	nw.	18	16	5	10	4.9	T.	0.0
Cape Henry	18	8	54	30.11	30.13		43.2		66	17	49	29	10	37	29	40	36	78	3.98	+0.5	13	9,082	n.	43	n.	8	12	7	12	5.7	T.	0.0
Lynchburg	681	153	188	29.40	30.17	+.03	40.6	+1.1	62	17	51	20	24	30	35	34	27	65	1.02	−2.2	6	3,588	w.	26	nw.	18	12	11	8	5.3	T.	0.0
Norfolk	91	170	205	30.06	30.16	+.03	44.6	+1.5	65	1	51	29	9	38	27	39	34	72	3.85	+0.5	12	8,156	ne.	32	nw.	18	10	5	16	5.9	T.	0.0
Richmond	144	11	52	30.01	30.18	+.04	41.0	+1.2	63	17	51	18	10	31	33	35	30	74	1.46	−1.8	8	4,305	ne.	29	sw.	17	13	5	13	5.4	1.2	0.0
Wytheville	2,304	49	55	27.72	30.18	+.03	36.4	+1.1	60	4	46	15	23	26	34	30	26	73	0.76	−2.2	8	3,941	w.	25	w.	17	12	7	12	5.4	1.2	0.0
South Atlantic States							48.0	+0.6										74	2.42	−0.8										5.3		
Asheville	2,253	70	84	27.75	30.18	+.02	39.0	+1.2	61	4	49	19	10	29	34	33	29	73	0.55	−2.5	7	5,386	nw.	28	se.	17	16	3	12	4.7	1.1	0.0
Charlotte	779	55	62	29.31	30.17	+.01	44.3	+1.3	67	4	53	26	9	35	30	39	34	72	0.88	−3.0	5	3,268	ne.	18	w.	29	13	7	11	5.0	T.	0.0
Greensboro	886	5	56	29.20	30.18		39.0		63	4	51	14	10	27	37	33	30	80	0.55		5	4,382	ne.	29	sw.	17	14	5	12	5.4	T.	0.0
Hatteras	11	11	50	30.09	30.10	−.03	49.2	−0.9	71	17	55	32	11	44	23	46	44	87	10.09	+5.9	18	10,521	n.	42	w.	7	11	6	14	5.9	0.0	0.0
Raleigh	376	103	110	29.75	30.17	+.02	44.3	+1.3	64	17	53	25	22	36	27	39	34	73	1.48	−1.7	8	4,256	ne.	20	sw.	17	10	8	13	5.8	0.1	0.0
Wilmington	78	81	91	30.07	30.16	+.01	48.8	−0.3	71	17	57	30	10	41	26	44	41	82	3.58	+0.8	13	4,583	n.	20	sw.	18	8	9	14	6.1	0.0	0.0
Charleston	48	11	92	30.10	30.15	.00	52.3	+0.6	73	14	59	34	10	45	23	46	41	72	1.09	−1.6	6	6,851	n.	25	n.	8	6	14	11	5.8	0.0	0.0
Columbia, S. C.	351	41	57	29.79	30.18	+.02	47.3	+0.1	70	5	57	27	10	38	30	41	35	70	1.82	−1.1	5	3,990	ne.	24	s.	17	10	13	8	5.0	0.0	0.0
Due West	711	10	55	29.40	30.20		44.4		68	5	54	22	10	34	33				1.20		6	5,416	ne.	30	w.	17	12	8	11	4.8	0.0	0.0
Greenville, S. C.	1,039	139	146	29.04	30.16		44.8	+2.6	66	4	53	25	9	36	32	38	32	66	1.51		8	5,149	ne.	30	sw.	17	14	6	11	4.8	T.	0.0
Augusta	182	62	77	29.97	30.17	+.01	48.8	+0.7	72	4	59	26	10	39	32	42	37	74	2.34	−0.9	6	2,925	nw.	20	w.	29	14	10	7	4.6	0.0	0.0
Savannah	65	150	194	30.09	30.16	+.01	53.4	+1.0	76	29	62	32	23	45	29	46	41	72	1.08	−1.8	5	7,005	ne.	31	nw.	29	12	7	12	5.2	0.0	0.0
Jacksonville	43	209	245	30.10	30.15	+.01	55.6	−0.7	75	29	63	32	23	48	28	49	45	76	1.34	−1.7	7	7,018	n.	32	w.	27	12	7	12	5.4	0.0	0.0
Florida Peninsula							66.0	−0.4										79	1.19	−0.7										3.8		
Key West	22	10	64	30.08	30.10	+.02	69.4	−0.9	83	2	75	53	9	64	16	64	62	84	2.26	+0.6	2	5,926	ne.	25	n.	8	24	7	0	2.5	0.0	0.0
Miami	25	71	164	30.09	30.12		67.3	−0.7	81	2	74	46	29	60	25	61	58	77	0.74	−1.3	2	6,565	nw.	23	nw.	25	15	13	3	3.7	0.0	0.0
Tampa	35	79	87	30.10	30.13	+.01	61.4	+0.3	82	5	70	38	23	53	29	54	51	77	0.56	−1.5	4	3,898	ne.	19	e.	13	15	5	11	4.7	0.0	0.0
Titusville	44	5		30.07	30.12		59.6		82	20	67	35	10	52	31				0.64		4		nw.				13	7	11	4.4	0.0	0.0
East Gulf States							49.3	−0.2										72	2.77	−1.9										4.9		
Atlanta	1,173	190	216	28.91	30.17	+.01	45.2	+0.5	67	4	53	24	9	37	28	39	34	69	0.82	−3.9	8	7,057	nw.	31	nw.	17	13	8	10	4.8	T.	0.0
Macon	370	78	87	29.78	30.18	+.02	47.6	+0.1	71	13	59	25	23	37	34	41	36	73	2.75	−1.7	7	3,807	nw.	19	nw.	18	15	6	10	4.7	T.	0.0
Thomasville	273	49	58	29.86	30.17	+.02	52.9	+0.4	75	29	62	30	9	44	29	46	41	74	1.84	−1.8	7	2,825	n.	16	sw.	29	12	6	13	5.4	0.0	0.0
Apalachicola	36	42	49	30.12	30.16		54.3		73	29	61	33	9	48	23	50	47	82	2.07		6	5,272	n.	25	e.	13	14	8	9	4.5	0.0	0.0
Pensacola	56	149	185	30.12	30.18	+.03	53.2	−0.8	69	29	60	28	9	46	21	48	43	73	3.60	−1.0	8	8,597	n.	35	e.	13	11	6	14	5.4	0.0	0.0
Anniston	741	9	57	29.40	30.21	+.05	44.2	0.0	72	4	56	19	9	32	38				1.31	−3.2	8	3,249	nw.	19	nw.	17	15	10	6	4.0	0.0	0.0
Birmingham	700	11	48	29.41	30.20	+.04	46.6	+0.2	70	4	56	22	9	37	33	40	34	69	0.91	−3.7	5	4,375	n.	34	se.	13	13	11	7	4.6	0.0	0.0
Mobile	57	125	161	30.12	30.18	+.03	52.3	+0.1	74	29	61	26	9	44	28	47	42	74	5.82	+0.8	7	6,166	n.	29	se.	13	11	7	13	5.4	0.0	0.0
Montgomery	223	100	112	29.94	30.20	+.04	49.3	−0.1	71	4	59	27	9	40	30	43	37	68	1.96	−2.9	7	3,868	n.	26	se.	13	13	10	8	4.7	T.	0.0
Corinth	469	6					45.0		71	4	56	19	9	34	38				1.28		6		s.				10	18	3		T.	0.0
Meridian	375	87	95	29.78	30.19	+.03	47.0	−0.7	74	4	58	21	9	36	35	41	36	73	1.70	−3.5	8	3,404	nw.	21	se.	12	11	11	9	5.0	0.0	0.0
Vicksburg	247	65	73	29.91	30.20	+.05	49.2	−0.8	73	4	58	27	9	40	24	43	36	67	3.66	−1.7	6	4,641	se.	24	nw.	17	13	10	8	4.5	0.0	0.0
New Orleans	53	76	84	30.12	30.18	+.05	54.7	−0.9	76	4	62	33	9	47	25	49	44	75	6.06	+1.3	7	4,012	ne.	20	ne.	20	11	7	13	5.4	0.0	0.0
West Gulf States							50.3	−0.1										73	3.92	+1.0										4.5		
Shreveport	249	77	93	29.91	30.19	+.06	49.4	+0.3	75	4	59	28	8	40	27	42	36	66	4.86	+0.6	6	4,362	se.	22	nw.	17	19	6	6	3.6	0.0	0.0
Bentonville	1,303	11	44	28.73	30.14	+.01	39.8	+2.3	72	28	50	16	8	30	28				2.96		8		s.				15	10	6		1.0	1.0
Fort Smith	457	79	94	29.66	30.16	+.03	43.1	+1.0	74	28	53	23	20	34	38	37	32	72	1.67	−1.1	6	5,766	e.	34	w.	26	17	4	10	4.3	T.	0.0
Little Rock	357	136	144	29.78	30.16	+.02	44.2	0.0	70	28	53	25	9	36	30	38	32	67	5.68	+1.4	8	6,004	sw.	31	nw.	26	19	5	7	3.8	0.0	0.0
Austin	605	136	148	29.52	30.16		50.8	−0.2	81	4	62	29	21	40	35	44	39	71	2.68	0.0	8	4,985	n.	28	nw.	17	14	7	10	4.5	0.0	0.0
Brownsville	57	53	61	30.07	30.13		60.6	−0.6	81	4	69	36	23	53	25	55	53	83	1.64	+0.1	9	4,768	n.	25	n.	17	9	8	14	5.8	0.0	0.0
Corpus Christi	20	11	73	30.14	30.16	+.04	57.0	−1.0	76	4	64	35	21	50	26	53	50	83	4.78	+3.5	8	6,215	n.	34	nw.	17	8	8	15	6.2	0.0	0.0
Dallas	512	220	227	29.61	30.17		47.4		78	28	57	25	20	38	34				6.68		9	8,299	se.	41	w.	31	22	2	7	3.5	0.0	0.0
Fort Worth	670	106	114	29.43	30.16	+.04	48.2	+0.7	81	28	58	29	20	38	34	42	36	67	5.50	+3.7	7	5,549	nw.	27	nw.	31	16	6	9	4.4	0.0	0.0
Galveston	54	106	114	30.12	30.18	+.02	54.8	−1.6	75	4	61	38	22	49	20	51	48	81	4.20	+0.4	9	6,132	n.	34	nw.	17	13	13	5	4.0	0.0	0.0
Groesbeck	461	11	56	29.67	30.16		48.4		75	4	59	27	9	38	32				4.97		7	6,588	n.	27	nw.	16	14	9	8	4.1	0.0	0.0
Houston	138	292	314	30.03	30.18		54.0	−0.4	80	4	62	33	8	45	25				4.37	+0.1	11	8,418	nw.	39	nw.	17	11	9	11	5.0	0.0	0.0
Palestine	510	64	72	29.64	30.18	+.06	49.2	−0.7	76	4	60	26	8	39	30	43	37	69	5.56	+1.9	7	4,815	s.	24	nw.	17	16	8	7	3.8	0.0	0.0
Port Arthur	34	58	66	30.14	30.17		53.8		75	4	62	33	23	46	26				3.24		9	4,470	n.	20	n.	17	11	9	11	5.2	0.0	0.0
San Antonio	693	119	132	29.42	30.17	+.06	53.5	−0.2	85	4	63	31	20	44	33	46	40	69	2.95	+1.3	12	4,104	ne.	27	nw.	17	12	9	10	5.0	0.0	0.0
Taylor	583	55	63	29.58	30.21	+.10	49.3	−1.3	79	4	60	28	21	39	35				3.19	+0.6	9	4,919	nw.	25	sw.	28	13	11	7	4.4	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, December, 1928*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Ohio Valley and Tennessee	Ft.	Ft.	Ft.	In.	In.	In.	°F. 38.8	°F. +2.2	°F		°F	°F.		°F	°F	°F	°F	% 72	In. 2.18	In. −1.4		Miles								0-10 5.4	In.	In.
Chattanooga	762	190	215	29.36	30.19	+.03	43.6	+0.3	68	4	53	24	9	35	35	37	29	60	1.52	−3.6	9	4,504	sw.	31	nw.	17	13	9	9	4.9	0.0	0.0
Knoxville	995	102	111	29.10	30.19	+.03	41.5	+1.2	65	4	51	23	10	32	31	36	32	75	1.15	−3.4	8	3,464	ne.	28	sw.	28	11	7	13	5.5	T.	0.0
Memphis	399	76	97	29.73	30.16	+.01	44.8	+1.2	70	28	52	23	8	37	23	39	33	67	4.13	−0.4	7	5,116	sw.	25	nw.	17	18	5	8	4.0	0.0	0.0
Nashville	546	168	191	29.59	30.19	+.04	42.8	+1.8	71	28	53	22	6	33	43	37	30	66	1.38	−2.8	7	5,647	w.	34	w.	17	13	9	9	4.4	T.	0.0
Lexington	989	193	230	29.09	30.19	+.05	39.4	+3.6	60	28	47	14	21	32	31	...	...	...	1.92	−1.4	10	8,262	sw.	40	nw.	17	14	6	11	4.5	T.	0.0
Louisville	525	188	234	29.59	30.19	+.05	39.2	+1.6	63	28	47	15	21	31	32	35	31	76	3.31	−0.4	8	6,131	s.	30	w.	17	16	6	9	4.3	T.	0.0
Evansville	431	76	116	29.70	30.19	+.06	39.8	+2.7	66	28	47	18	21	32	33	35	30	72	2.78	−0.8	9	5,831	s.	29	sw.	28	15	6	10	4.9	0.4	0.0
Indianapolis	822	194	230	29.23	30.14	+.02	35.4	+3.2	55	2	42	8	21	28	23	31	27	73	2.19	−0.8	10	6,810	s.	34	w.	20	9	8	14	6.1	0.5	0.0
Royal Center	736	11	55	29.31	30.14	...	31.8	...	51	11	39	3	21	24	28	...	...	...	1.77	...	8	6,075	sw.	35	w.	20	6	9	16	6.9	0.7	0.0
Terre Haute	575	96	129	29.51	30.14	...	35.5	...	56	28	43	9	21	28	26	32	27	75	1.91	...	9	5,596	s.	24	s.	26	11	7	13	5.8	2.9	0.0
Cincinnati	627	11	51	29.46	30.17	+.04	36.8	+3.4	58	13	45	9	21	29	29	32	29	77	2.56	−0.4	9	4,283	sw.	24	w.	17	11	7	13	5.5	1.1	0.0
Columbus	822	179	222	29.25	30.15	+.03	36.4	+4.0	58	13	43	9	21	30	21	32	28	76	2.07	−0.7	8	5,999	s.	33	w.	18	10	5	16	5.7	T.	0.0
Dayton	899	137	173	29.16	30.15	...	36.3	+3.7	59	13	43	9	21	30	26	32	27	73	2.09	−0.7	7	5,374	sw.	28	sw.	3	9	9	13	5.7	T.	0.0
Elkins	1,947	59	67	28.06	30.21	+.09	33.8	+1.1	63	13	45	9	22	23	40	28	24	82	2.68	−0.7	9	2,840	w.	27	w.	17	8	6	17	6.7	2.7	0.0
Parkersburg	637	77	82	29.51	30.18	+.04	37.2	+2.0	62	13	46	14	21	28	34	31	26	72	1.59	−1.2	9	3,021	sw.	24	nw.	17	11	5	15	6.2	0.1	0.0
Pittsburgh	842	353	410	29.22	30.15	+.04	35.8	+1.6	58	13	43	10	21	29	26	32	26	70	1.18	−1.7	7	6,036	sw.	37	w.	17	10	8	13	5.9	T.	0.0
Lower Lake Region							33.6	+4.4										76	1.30	−1.5										7.4		
Buffalo	767	247	280	29.23	30.08	+.02	33.5	+3.7	51	13	38	11	22	29	17	31	28	80	1.87	−1.5	16	11,993	w.	58	w.	21	3	7	21	7.8	13.2	T.
Canton	448	10	61	29.57	30.06	...	28.6	+5.9	51	17	35	3	21	23	25	...	...	...	1.22	−2.4	11	6,380	sw.	34	w.	18	6	4	21	7.5	4.5	T.
Ithaca	836	5	100	29.16	30.10	...	33.2	...	54	17	39	9	22	27	24	29	25	75	0.13	−2.2	5	6,103	nw.	34	se.	3	5	9	17	7.0	0.3	0.0
Oswego	335	76	91	29.71	30.09	+.03	33.6	+4.6	55	17	39	11	22	28	26	31	27	80	1.76	−1.7	10	7,113	s.	31	nw.	21	3	7	21	8.1	11.4	0.0
Rochester	523	86	102	29.52	30.11	+.05	34.0	+4.7	53	17	39	10	22	29	18	30	25	72	0.78	−1.9	12	5,198	sw.	30	w.	18	4	5	22	7.6	2.6	0.0
Syracuse	596	65	79	29.45	30.11	+.04	34.6	+6.3	57	17	40	15	9	29	27	...	...	...	0.91	−1.7	9	4,968	sw.	26	sw.	21	4	8	19	7.4	7.5	1.0
Erie	714	130	166	29.32	30.11	+.04	35.4	+3.5	57	13	40	15	22	30	20	31	26	70	0.66	−2.2	8	9,191	s.	42	sw.	20	4	3	24	8.1	3.8	0.0
Cleveland	762	190	201	29.28	30.13	+.04	35.2	+4.0	59	13	41	11	21	29	19	31	26	71	1.41	−1.0	10	8,152	sw.	44	w.	20	7	4	20	6.9	1.9	0.0
Sandusky	629	5	67	29.43	30.14	+.05	34.1	+2.9	51	17	40	9	21	28	23	...	...	...	1.81	−0.5	11	5,710	sw.	30	w.	20	6	6	19	7.1	0.7	0.0
Toledo	628	208	243	29.43	30.13	+.05	34.0	+3.6	52	13	40	9	21	28	21	30	26	75	2.36	0.0	11	8,335	sw.	38	w.	20	8	6	17	6.6	1.0	0.0
Fort Wayne	856	113	124	29.16	30.12	...	33.4	+6.1	53	11	40	6	21	26	25	30	26	79	1.75	...	6	5,533	sw.	28	w.	20	7	7	17	6.8	1.1	0.0
Detroit	730	218	258	29.30	30.11	+.04	32.9	+3.6	53	13	38	9	21	28	23	31	28	83	1.38	−1.0	11	6,839	sw.	36	sw.	20	4	8	19	7.4	2.6	T.
Upper Lake Region							28.3	+3.8										84	1.54	−0.6										7.5		
Alpena	609	13	92	29.36	30.05	+.03	29.2	+4.4	48	11	34	5	21	24	23	27	24	83	0.94	−1.1	10	6,619	sw.	33	se.	3	4	9	18	7.5	5.6	0.0
Escanaba	612	54	60	29.36	30.05	+.02	25.8	+3.4	49	16	31	−2	21	20	20	24	20	79	0.20	−1.6	4	6,007	sw.	23	nw.	20	7	7	17	6.3	1.9	1.0
Grand Haven	632	54	89	29.37	30.08	+.03	32.1	+2.8	47	12	37	13	23	27	22	30	27	83	2.63	+0.1	10	7,969	w.	40	w.	20	4	2	25	8.5	3.3	0.0
Grand Rapids	707	70	87	29.30	30.10	+.05	31.7	+3.2	48	12	37	9	21	27	24	29	26	80	2.79	+0.2	10	3,792	w.	28	w.	20	1	6	24	8.8	8.0	0.0
Houghton	668	64	99	29.25	30.00	−.02	25.6	+3.8	45	10	31	5	20	20	28	...	...	...	1.27	−1.2	11	5,814	w.	31	w.	16	4	4	23	8.0	11.4	1.6
Lansing	878	6	49	29.12	30.09	...	29.1	+1.9	46	11	35	2	22	23	23	28	27	92	1.81	−0.3	12	3,444	sw.	23	w.	20	6	3	22	7.7	8.2	T.
Ludington	637	60	66	29.34	30.05	...	32.2	...	47	12	36	12	21	28	18	31	29	87	1.55	...	11	7,386	w.	29	n.	20	4	7	20	7.7	6.4	0.0
Marquette	734	77	111	29.19	30.02	.00	27.0	+4.4	49	16	33	0	21	21	24	24	21	82	1.13	−1.5	12	6,487	w.	28	sw.	22	5	3	23	7.9	10.0	2.1
Port Huron	638	70	120	29.38	30.09	+.03	31.4	+3.8	48	11	36	9	22	26	22	29	26	84	1.19	−0.8	10	6,753	sw.	31	w.	20	5	7	19	7.1	3.5	0.0
Sault Sainte Marie	614	11	52	29.31	30.03	+.03	27.0	+6.5	41	16	32	−1	21	22	26	25	23	88	1.39	−0.9	15	5,287	se.	27	nw.	29	0	4	27	9.2	14.1	3.3
Chicago	673	7	131	29.36	30.11	+.03	32.2	+3.4	50	11	38	3	21	27	19	29	26	78	2.63	+0.6	15	6,500	sw.	32	sw.	3	8	6	17	6.5	3.3	0.0
Green Bay	617	109	141	29.37	30.06	+.02	26.2	+3.9	45	16	32	−6	21	20	23	25	22	83	0.92	−0.9	9	6,758	s.	24	nw.	20	6	10	15	6.7	1.9	0.4
Milwaukee	681	125	221	29.32	30.08	+.02	30.2	+4.1	52	11	36	−2	21	24	22	27	24	79	1.97	+0.2	8	8,540	sw.	43	se.	2	9	6	16	6.6	1.2	T.
Duluth	1,133	5	47	28.76	30.04	−.01	20.2	+4.3	40	24	27	−13	21	14	29	18	16	87	1.16	0.0	9	8,291	nw.	35	nw.	26	9	6	16	6.2	11.4	1.5
North Dakota							20.9	+8.5										83	0.39	−0.2										6.8		
Moorhead	940	50	58	28.99	30.05	−.03	22.2	+10.7	46	10	30	−15	21	14	30	20	18	85	0.44	−0.3	8	5,726	s.	25	nw.	26	10	9	12	6.0	5.2	1.7
Bismarck	1,674	8	57	28.21	30.07	−.01	22.5	+7.8	48	27	32	−12	4	12	36	20	16	80	0.24	−0.3	8	5,478	nw.	32	nw.	18	10	10	11	5.6	2.8	T.
Devils Lake	1,478	11	44	28.39	30.03	−.03	19.0	+9.5	45	10	27	−17	20	11	32	17	15	86	0.31	−0.1	10	6,266	sw.	34	n.	18	11	7	13	5.6	3.5	1.0
Ellendale	1,457	10	56	28.43	30.05	...	22.2	...	51	27	32	−10	21	12	32	...	...	...	0.39	...	10	8,846	nw.	37	nw.	18	12	12	7	5.1	4.7	0.4
Grand Forks	833	12	67	...	...	...	20.6	...	47	10	28	−17	21	13	28	19	...	...	0.47	...	9	...	nw.	...	s.	8	6	11	14	...	7.4	2.6
Williston	1,878	41	48	28.01	30.07	+.01	19.8	+6.0	44	10	30	−21	4	10	31	18	15	80	0.56	0.0	5	4,938	w.	28	w.	26	12	8	11	5.0	5.6	0.3
Upper Mississippi Valley							31.0	+4.2										81	1.58	−0.1										5.9		
Minneapolis	918	102	208	29.03	30.04	...	25.6	+6.0	45	10	33	−11	21	18	31	...	...	...	0.43	−0.6	9	7,204	s.	33	nw.	26	7	9	15	6.4	3.6	0.4
St. Paul	837	236	261	29.12	30.06	−.02	25.0	+6.0	46	10	32	−8	21	18	30	...	...	...	0.41	−0.6	10	7,197	se.	31	nw.	26	6	8	17	6.8	5.2	0.8
La Crosse	714	11	48	29.28	30.08	.00	26.9	+4.6	47	12	34	−10	21	20	31	25	22	83	1.10	−0.2	8	3,509	s.	14	nw.	20	9	6	16	6.5	2.5	T.
Madison	974	70	78	29.01	30.10	+.02	27.0	+4.2	51	11	33	−4	21	20	23	25	23	85	1.64	0.0	9	5,515	s.	22	sw.	3	7	8	16	6.3	0.5	T.
Wausau	1,247	4	64	...	30.06	...	24.2	...	43	12	30	−11	21	18	27	...	...	...	0.46	...	8	4,225	w.	18	e.	2	6	8	17	...	3.0	1.0
Charles City	1,015	10	51	28.98	30.10	.00	26.3	+5.9	46	11	33	1	20	19	24	24	22	86	1.13	−0.2	3	4,655	nw.	21	nw.	18	8	6	17	6.5	T.	T.
Davenport	606	71	79	29.43	30.12	+.02	31.3	+4.2	53	11	38	5	5	25	22	28	25	80	1.64	+0.2	10	4,433	s.	22	w.	3	11	7	13	5.7	2.6	T.
Des Moines	861	84	97	29.16	30.10	−.01	29.8	+3.8	50	27	38	0	5	22	32	27	24	83	1.03	−0.2	5	4,478	sw.	23	sw.	26	9	7	15	6.0	1.6	0.0
Dubuque	700	81	96	29.32	30.10	.00	29.1	+4.4	50	11	36	1	21	22	26	26	23	81	1.09	−0.4	4	4,092	s.	19	n.	31	6	11	14	6.5	0.9	0.0
Keokuk	614	64	78	29.44	30.14	+.02	33.0	+3.4	52	26	40	5	5	26	25	30	26	78	1.85	+0.4	6	4,948	s.	34	w.	3	12	5	14	5.5	2.3	T.
Cairo	358	87	93	29.77	30.16	+.01	40.6	+2.8	67	28	49	21	8	33	30	36	31	74	3.26	−0.1	8	5,497	s.	29	s.	26	14	7	10	4.6	T.	0.0
Peoria	609	11	45	29.45	30.14	+.03	32.0	+3.9	53	11	39	5	5	25	25	29	27	85	2.53	+0.8	8	4,409	s.	30	w.	3	11	7	13	5.6	1.3	0.0
Springfield, Ill	636	154	191	29.42	30.12	.00	34.6	+2.9	57	28	42	9	21	27	22	31	28	83	1.94	−0.2	9	7,975	s.	34	w.	3	9	9	13	5.9	0.2	0.0
Hannibal	534	74	109	29.54	30.13	+.01	34.8	+3.3	56	28	43	11	5	27	29	...	...	...	1.92	+0.3	7	5,574	sw.	31	sw.	2	13	6	12	5.0	1.9	0.0
St. Louis	568	265	303	29.52	30.14	+.01	38.6	+3.9	75	28	46	16	5	31	35	34	29	72	2.22	0.0	8	8,030	s.	36	sw.	26	14	6	11	4.8	T.	0.0
Missouri Valley							32.7	+4.9										75	0.97	−0.1										5.2		
Columbia, Mo	784	6	84	29.26	30.12	.00	36.2	+3.0	66	28	44	14	5	28	29	...	...	...	2.04	0.0	8	5,369	sw.	23	w.	2	10	9	12	5.4	2.1	0.9
Kansas City	963	161	181	29.07	30.13	+.01	36.6	+4.1	57	28	44	15	22	30	22	32	27	72	1.83	+0.5	8	6,989	s.	32	w.	2	11	8	12	5.4	6.1	3.7
St. Joseph	967	11	49	29.05	30.12	...	34.7	...	54	27	42	13	22	28	26	31	27	77	0.50	...	6	5,635	nw.	28	nw.	3	12	7	12	5.3	1.3	0.6
Springfield, Mo	1,324	98	104	28.71	30.15	+.02	38.0	+1.8	75	28	47	15	5	30	33	33	28	74	2.70	0.0	7	7,004	nw.	32	nw.	26	15	5	11	4.7	0.6	0.5
Iola	984	11	50	29.05	30.14	+.02	37.2	+3.3	64	28	46	14	5	28	30	...	...	...	2.23	+1.2	9	3,866	s.	24	nw.	26	11	6	14	5.8	2.7	1.0
Topeka	987	92	107	...	...	...	36.6	+4.6	61	27	44	15	31	29	29	...	...	...	1.24	+0.4	4	6,532	sw.	26	nw.	26	11	7	13	5.1	6.6	3.8
Lincoln	1,189	11	81	28.81	30.12	.00	31.2	+3.6	57	27	39	9	31	23	29	28	23	75	0.03	−0.6	2	6,192	s.	31	w.	2	11	7	13	5.5	T.	0.0
Omaha	1,105	115	122	28.90	30.12	+.01	31.3	+4.9	55	27	38	9	5	24	26	28	24	74	0.40	−0.5	5	5,337	nw.	30	nw.	31	12	7	12	5.1	1.4	0.0
Valentine	2,598	47	54	27.32	30.13	+.03	29.7	+5.1	67	27	42	1	31	17	45	24	19	72	0.66	0.0	9	5,877	w.	32	nw.	26	15	8	8	3.9	9.9	0.2
Sioux City	1,135	94	164	28.85	30.11	−.01	29.9	+6.8	57	27	38	6	5	22	31	27	23	78	0.14	−0.6	3	7,696	nw.	36	nw.	26	10	10	11	5.5	1.5	T.
Huron	1,306	59	74	28.65	30.10	.00	26.4	+7.7	62	27	37	−2	5	16	44	23	19	77	0.09	−0.5	4	5,596	nw.	25	nw.	18	13	10	8	4.8	0.9	T.
Pierre	1,572	70	75	...	30.12	+.02	28.4	+6.6	66	27	39	−2	4	18	42	...	...	76	0.19	−0.3	4	5,142	nw.	34	nw.	18	17	5	9	...	2.4	T.
Yankton	1,233	49	57	28.73	30.09	−.02	30.4	+7.6	64	27	40	3	31	21	39	...	...	...	0.10	−0.7	4	5,149	nw.	27	nw.	18	10	10	11	5.6	0.6	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, December, 1928*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	° F.	° F.	° F		° F	° F.		° F	° F	° F	° F	%	In.	In.		Miles								0–10	In.	In.
Northern Slope							23.3	−0.6										75	0.50	−0.4										5.2		
Billings	3,140	5	-----	-----	-----	-----	27.2	-----	62	27	38	−11	4	16	40	-----	-----	-----	0.62	-----	5	-----	nw.	-----	-----	-----	17	7	7	-----	6.4	2.5
Havre	2,505	11	44	27.38	30.11	+0.06	23.9	+3.5	52	23	35	−31	4	13	50	21	17	76	0.85	+0.2	7	5,477	sw.	28	sw.	17	4	18	9	5.9	11.2	4.2
Helena	4,110	87	112	25.85	30.20	+.07	23.7	−0.7	51	27	33	−10	4	15	30	21	17	76	0.94	+0.1	9	4,096	sw.	31	sw.	25	4	15	12	6.6	13.3	2.1
Kalispell	2,973	48	56	27.04	30.22	+.15	22.0	−2.9	46	9	28	−3	4	16	25	21	19	87	1.00	−0.8	11	2,709	nw.	23	sw.	25	2	7	22	8.4	11.8	7.3
Miles City	2,371	48	55	27.51	30.16	+.06	23.5	+2.5	49	27	34	−16	4	13	32	21	17	78	0.40	−0.2	10	3,662	s.	30	nw.	18	10	11	10	5.2	5.9	1.2
Rapid City	3,259	50	58	26.62	30.15	+.06	30.8	+3.9	66	27	43	−1	4	19	43	25	17	59	0.10	−0.4	5	5,314	nw.	34	n.	18	15	11	5	4.0	1.0	0.4
Cheyenne	6,088	84	101	23.99	30.17	+.08	26.8	−1.7	60	27	37	−3	4	16	32	21	12	56	0.17	−0.4	4	9,199	w.	39	w.	25	20	6	5	3.0	2.2	0.2
Lander	5,372	60	68	24.68	30.35	+.20	11.0	−9.4	53	27	24	−20	4	−2	45	8	6	88	0.16	−0.5	3	2,321	w.	35	sw.	27	18	11	2	3.4	1.7	7.0
Sheridan	3,790	10	47	26.12	30.18	-----	21.6	-----	62	27	34	−13	4	10	36	19	14	74	0.36	-----	9	2,923	s.	28	nw.	18	12	11	8	4.9	4.4	2.5
Yellowstone Park	6,241	11	48	23.92	30.30	+.14	19.6	−2.0	42	27	29	−1	19	10	30	16	12	75	0.84	−1.0	12	4,845	s.	32	sw.	27	5	10	16	6.8	10.7	6.4
North Platte	2,821	11	51	27.12	30.16	+.06	28.3	+1.6	63	27	39	3	5	18	39	24	20	77	0.08	−0.4	2	4,385	w.	24	n.	18	16	7	8	4.1	0.8	T.
Middle Slope							35.4	+1.8										69	0.78	0.0										4.0		
Denver	5,292	106	113	24.75	30.18	+.10	31.2	−1.1	70	27	43	2	5	20	43	24	14	56	0.06	−0.7	2	4,709	s.	26	w.	26	20	11	0	2.4	0.1	T.
Pueblo	4,685	80	86	25.34	30.17	+.09	30.7	−0.8	71	27	44	2	5	17	44	24	18	64	0.21	−0.2	3	3,760	nw.	37	nw.	28	23	7	1	2.1	0.9	0.0
Concordia	1,392	50	58	28.64	30.16	+.05	35.3	+4.6	63	27	44	15	31	26	33	30	24	71	0.01	−0.6	1	5,193	s.	33	nw.	26	11	8	12	5.1	T.	0.0
Dodge City	2,509	11	51	27.50	30.18	+.08	35.7	+3.1	69	27	46	13	18	25	43	30	25	74	0.82	+0.2	4	5,758	nw.	30	nw.	2	18	6	7	3.5	5.1	0.4
Wichita	1,358	139	158	28.66	30.14	+.03	37.6	+3.0	65	28	46	17	31	30	28	34	30	79	1.58	+0.8	5	7,858	s.	38	nw.	26	14	8	9	4.4	5.3	3.8
Broken Arrow	765	11	56	29.31	30.15	-----	40.4	-----	72	28	50	20	5	31	33	-----	-----	-----	1.23	-----	6	8,008	n.	34	nw.	26	12	7	12	5.2	0.3	T.
Oklahoma City	1,214	10	47	28.84	30.16	+.05	41.6	+2.3	71	28	51	21	5	32	35	36	30	72	2.01	+0.3	8	6,755	s.	23	nw.	26	12	10	9	5.0	0.5	0.2
Southern Slope							44.3	+0.2										66	0.61	−0.3										3.9		
Abilene	1,738	10	52	28.32	30.18	+.07	46.0	0.0	78	28	58	22	20	34	39	38	30	64	0.83	−0.5	5	5,918	s.	25	s.	15	16	4	11	4.5	0.0	0.0
Amarillo	3,676	10	49	26.34	30.16	+.07	39.6	+2.6	70	28	50	19	5	29	36	32	27	68	0.51	−0.3	4	5,461	nw.	30	w.	28	19	3	9	3.5	3.0	0.0
Del Rio	944	64	71	29.14	30.15	+.05	51.3	−0.9	76	4	62	27	23	41	37	44	38	67	0.47	−0.4	7	4,655	se.	29	nw.	12	17	6	8	4.2	0.0	0.0
Roswell	3,566	75	85	26.45	30.15	+.08	40.4	−0.8	74	28	54	13	20	26	45	33	26	64	0.64	+0.1	3	3,483	n.	28	w.	28	16	11	4	3.4	T.	0.0
Southern Plateau							41.2	−0.5										54	0.31	−0.3										2.4		
El Paso	3,778	152	175	26.28	30.14	+.11	44.8	−0.1	69	28	56	19	20	34	34	36	25	51	0.13	−0.4	5	5,445	w.	39	nw.	11	20	6	5	2.7	T.	0.0
Santa Fe	7,013	38	53	23.27	30.19	+.13	30.8	+0.1	59	27	42	3	20	20	34	22	14	57	0.23	−0.5	5	3,871	ne.	20	n.	26	19	9	3	2.7	2.1	0.0
Flagstaff	6,907	10	59	23.38	30.15	+.09	26.0	−2.4	59	27	40	−14	17	12	52	21	-----	69	1.65	-----	7	-----	e.	-----	nw.	30	17	12	2	-----	19.5	T.
Phoenix	1,108	10	82	28.91	30.09	+.05	51.4	−0.6	77	27	65	28	20	38	39	42	32	54	1.01	+0.4	5	1,799	e.	14	se.	11	21	6	4	2.4	0.0	0.0
Yuma	141	9	54	29.96	30.11	+.06	55.4	+0.2	75	9	67	35	15	44	32	44	29	40	T.	−0.5	0	4,287	n.	22	n.	30	24	5	2	1.9	0.0	0.0
Independence	3,957	6	27	26.08	30.20	+.08	39.0	−0.3	65	28	52	16	17	26	36	39	-----	-----	0.19	−0.6	4	-----	nw.	-----	-----	-----	20	5	6	-----	T.	0.0
Middle Plateau							27.0	−3.2										72	0.57	−0.3										4.0		
Reno	4,532	74	81	25.57	30.24	+.09	31.8	−1.9	63	26	43	5	23	20	38	28	23	69	0.32	−0.7	8	3,375	w.	39	w.	10	16	8	7	4.0	2.0	0.0
Tonopah	6,090	12	20	-----	-----	-----	27.5	-----	47	7	32	8	18	23	16	24	17	62	0.58	-----	4	-----	se.	-----	-----	-----	-----	-----	-----	-----	-----	-----
Winnemucca	4,344	18	56	25.76	30.29	+.11	27.8	−2.2	59	27	42	−3	22	14	46	23	17	67	0.35	−0.7	8	4,028	ne.	35	ne.	28	14	15	2	3.7	1.9	0.0
Modena	5,473	10	43	24.71	30.26	+.14	22.7	−5.4	56	27	36	−11	20	9	38	18	15	81	0.52	−0.1	6	5,155	w.	36	sw.	13	19	8	4	3.1	9.6	T.
Salt Lake City	4,360	163	203	25.78	30.28	+.13	28.6	−3.3	60	27	35	9	20	23	31	25	21	75	0.54	−0.9	8	3,422	nw.	36	nw.	25	6	14	11	5.6	6.2	0.1
Grand Junction	4,602	60	68	25.54	30.26	+.16	24.2	−3.3	44	13	34	−2	18	14	31	21	18	79	1.12	+0.7	9	2,622	se.	21	se.	13	19	6	6	3.4	12.6	0.6
Northern Plateau							28.8	−2.7										79	1.04	−0.6										6.7		
Baker	3,471	48	53	26.50	30.30	+.14	23.8	−3.5	51	27	33	−1	21	15	26	22	18	78	0.51	−1.0	10	4,331	se.	21	se.	25	8	9	14	6.0	6.5	1.2
Boise	2,739	78	86	27.37	30.34	+.14	28.3	−3.8	61	27	37	4	22	20	43	25	20	74	1.11	−0.5	8	3,006	se.	24	se.	24	13	8	10	5.1	2.7	T.
Lewiston	757	40	48	29.39	30.23	+.10	34.4	−1.3	57	29	41	16	5	28	22	-----	-----	-----	0.39	−1.1	9	2,226	e.	19	nw.	1	5	7	19	7.3	0.9	0.0
Pocatello	4,477	60	68	25.60	30.31	+.12	22.5	−5.2	51	27	30	−10	21	14	26	20	16	77	1.10	+0.2	13	5,714	se.	36	sw.	28	12	6	13	5.5	14.0	3.0
Spokane	1,929	101	110	28.12	30.24	+.16	29.6	−0.9	52	9	35	10	4	24	17	29	26	84	1.81	−0.4	9	3,009	sw.	29	sw.	25	3	5	23	8.3	8.0	0.7
Walla Walla	991	57	65	29.13	30.24	+.12	34.0	−1.5	60	10	39	16	6	29	28	31	28	80	1.32	−0.7	10	2,762	s.	25	s.	10	4	7	20	7.8	3.7	0.3
North Pacific Coast Region							41.8	−0.4										84	4.69	−2.8										7.5		
North Head	211	11	56	29.86	30.10	+.07	44.2	+0.1	53	22	49	33	18	40	14	42	40	88	4.75	−3.6	16	11,175	se.	72	s.	9	10	5	16	6.3	0.0	0.0
Port Angeles	29	8	53	-----	30.09	-----	39.4	-----	52	12	44	25	5	34	17	-----	-----	-----	2.85	−2.3	14	3,834	sw.	25	w.	25	5	4	22	-----	0.0	0.0
Seattle	125	215	250	29.98	30.11	+.10	41.4	−0.3	54	9	46	29	20	37	18	39	35	78	3.49	−1.9	16	5,537	se.	40	s.	25	5	5	21	7.4	0.0	0.0
Tacoma	194	172	201	29.92	30.13	+.12	40.2	−0.4	56	8	46	24	5	35	19	-----	-----	-----	3.25	−3.6	14	4,589	s.	35	s.	25	5	4	22	7.7	0.0	0.0
Tatoosh Island	86	9	53	29.94	30.04	+.08	43.9	0.0	53	7	46	36	3	42	7	42	41	89	6.53	−8.1	19	12,770	e.	52	s.	8	9	4	18	6.9	0.0	0.0
Yakima	1,076	58	67	29.04	30.23	-----	30.3	-----	53	9	37	11	5	24	29	28	25	82	1.81	-----	10	-----	n.	-----	-----	-----	5	4	22	7.7	14.3	7.8
Medford	1,425	4	80	28.63	30.18	-----	36.6	-----	58	26	44	16	23	29	29	34	32	87	2.84	-----	9	-----	se.	31	se.	24	1	9	21	8.2	T.	0.0
Portland, Oreg.	153	68	106	29.99	30.16	+.09	40.1	−1.1	59	9	45	25	19	35	18	37	34	80	7.51	+0.8	17	3,908	se.	17	e.	6	5	6	20	7.6	0.2	0.0
Roseburg	510	75	99	29.60	30.16	+.05	40.8	−1.0	63	9	47	22	23	34	27	39	36	84	4.46	−0.9	13	2,630	s.	19	sw.	29	0	9	22	8.3	0.0	0.0
Middle Pacific Coast Region							46.2	−2.1										80	4.13	+0.1										4.9		
Eureka	62	73	89	30.09	30.16	+.04	48.1	−0.1	64	7	56	32	17	40	27	45	42	80	7.82	+1.5	12	3,729	se.	28	sw.	25	10	5	16	5.9	0.0	0.0
Red Bluff	330	54	58	29.83	30.20	+.06	43.3	−2.8	69	6	53	24	23	34	33	40	36	77	2.87	−1.5	7	3,232	nw.	24	s.	10	12	7	12	5.2	0.7	0.0
Sacramento	69	106	117	30.12	30.19	+.05	43.3	−2.9	62	4	50	25	22	36	29	42	40	88	2.66	−0.4	8	3,600	se.	30	se.	10	8	9	14	5.5	0.0	0.0
San Francisco	155	208	243	30.00	30.17	+.05	49.6	−1.7	63	5	55	36	23	44	19	46	42	76	4.89	+0.9	8	3,983	n.	42	nw.	10	15	8	8	4.3	0.0	0.0
San Jose	141	12	110	30.02	30.18	-----	46.8	−3.1	69	27	58	27	23	36	31	-----	-----	-----	2.40	−0.2	7	3,212	s.	30	se.	12	19	5	7	3.4	0.0	0.0
South Pacific Coast Region							53.0	+0.1										67	2.20	+0.2										3.8		
Fresno	327	89	98	29.84	30.21	+.08	44.1	−2.1	66	26	52	26	21	37	26	42	40	85	1.47	0.0	7	2,829	nw.	28	nw.	10	11	6	14	6.3	0.0	0.0
Los Angeles	338	159	191	29.75	30.12	+.05	58.8	+2.2	82	26	68	42	17	50	29	48	38	51	2.70	+0.1	5	3,638	ne.	28	nw.	11	21	5	5	2.4	0.0	0.0
San Diego	87	62	70	30.01	30.10	+.03	56.1	+0.1	74	26	65	38	19	47	27	49	42	64	2.42	+0.6	7	3,316	nw.	27	w.	11	19	8	4	2.7	0.0	0.0
West Indies																																
San Juan, P. R.	82	9	54	28.89	29.97	-----	76.4	+0.1	87	9	81	68	16	72	17	-----	-----	-----	4.75	−1.4	22	8,609	e.	35	e.	14	4	23	4	5.5	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, December, 1928*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Panama Canal	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0-10	In.	In.
Balboa Heights	118	7	97	[1] 29.75	[2] 29.83	-.01	79.8	-0.1	91	13	87	69	5	73	19	74	73	[2] 85	6.95	+2.6	16	[3] 4,703	nw.	[3] 27	nw.	8	1	20	10	6.6	0.0	0.0
Colon	38	7	97	[1] 29.84	[2] 29.84	-.01	80.5	+0.5	89	14	86	72	9	76	14	75	74	[2] 84	16.43	+5.3	27	[3] 8,448	n.	[3] 35	nw.	28	6	11	14	6.5	0.0	0.0
Alaska																																
Juneau	80	11	50	[4] 29.68	[4] 29.77		34.4		45	6	38	20	31	31	11	33	30	83	10.41		22	6,465	se.	35	e.	21	3	2	26	8.7	7.9	0.0
Hawaiian Islands																																
Honolulu	38	86	100	[4] 30.04	[4] 30.08		73.3		82	1	77	67	5	69	11	66	62	69	2.17	-1.8	15	7,521	e.	42	ne.	25	12	16	3	4.3	0.0	0.0

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District and station	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation total	Departure from normal	Days with 0.01, or more	Total movement	Prevailing direction	Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Miles City (March)	2,371	48	55	27.46	30.04	+0.02	38.0	+9.4	80	22	48	12	4	28	41	32	25	66	0.54	-0.2	6	3,206	s.	29	w.	24	8	11	12	6.2	3.7	0.0
Yakima (May)	1,071	5					63.8		98	25	81	28	2	47	46	50		49	0.20		4		nw.				16	14	1	3.7	0.0	0.0
Titusville (August)	44	5		29.97	30.02		81.6		98	22	90	70	19	73	28				7.32		12		e.				10	10	11	5.4	0.0	0.0
Billings (October)	3,140	5					45.4		86	9	60	19	30	31	48				2.35		7		nw.				18	4	9			

[1] 8 a. m. observation only. [2] Observations taken bi-hourly. [3] 4-cup anemometer. [4] Pressure not reduced to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, December, 1928*

Station	Altitude above mean sea level, Jan. 1, 1919	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Mean maximum	Temperature: Mean minimum	Temperature: Highest	Temperature: Lowest	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Total snowfall
	Feet	Inches	Inches	Inches	°F.	°F.	°F.	°F.	°F.	°F.	Inches	Inches	Inches
Cape Race, N. F	99				35.0		43.6	26.4	54	13	7.90		0.1
Sydney, C. B. I	48	29.89	29.94	+0.05	32.2	+4.0	37.7	26.6	55	14	7.03	+2.40	5.5
Halifax, N. S	88	29.89	30.00	+.04	33.5	+5.9	40.1	26.9	55	10	4.70	-0.42	2.4
Yarmouth, N. S	65	29.88	29.95	-.03	35.4	+4.7	41.1	29.7	54	15	6.33	+1.56	T.
Charlottetown, P. E. I	38	29.85	29.89	-.05	30.0	+5.7	35.0	25.0	52	10	3.47	-0.19	6.5
Chatham, N. B	28	29.83	29.87	-.07	23.0	+6.0	30.9	15.1	50	-8	2.93	-0.29	17.6
Father Point, Que	20												
Quebec, Que	296	29.69	30.03	+.02	23.3	+8.1	28.4	18.2	44	-4	2.95	-0.74	18.1
Doucet, Que	1,236				17.0		24.9	9.1	38	-27	2.81		28.0
Montreal, Que	187	29.82	30.04	+.01	26.8	+8.5	32.2	21.4	46	2	2.20	-1.45	13.0
Ottawa, Ont	236	29.80	30.08	+.06	25.0	+8.0	31.6	18.4	46	-4	2.06	-0.85	15.5
Kingston, Ont	285	29.76	30.08	+.04	31.3	+7.6	36.1	26.5	46	6	1.93	-1.31	1.0
Toronto, Ont	379	29.66	30.09	+.04	32.8	+5.8	37.5	28.2	47	13	1.25	-1.66	1.7
Cochrane, Ont	930				17.5		23.1	11.9	40	-24	0.85		6.8
White River, Ont	1,244	28.60	29.96	-.01	17.1	+7.4	24.4	9.8	42	-30	1.02	-0.69	8.2
London, Ont	808				29.9		35.1	24.6	48	3	2.83		9.5
Southampton, Ont	656	29.31	30.04	+.02	30.2	+3.5	35.1	25.4	44	4	3.43	-0.55	15.6
Parry Sound, Ont	688	29.32	30.03	+.02	26.7	+5.5	32.1	21.3	40	-5	4.65	+0.17	35.0
Port Arthur, Ont	644	29.29	30.02	+.03	21.4	+8.2	27.7	15.1	46	-7	0.58	-0.29	2.2
Winnipeg, Man	760												
Minnedosa, Man	1,690	28.12	30.01	-.01	16.4	+10.7	24.5	8.3	41	-24	0.43	-0.19	4.3
Le Pas, Man	860				11.1		20.2	2.1	42	-30	0.35		3.5
Qu'Appelle, Sask	2,115	27.68	30.02	+.02	17.7	+10.3	25.2	10.1	43	-20	0.20	-0.32	2.0
Moose Jaw, Sask	1,759				20.7		29.8	11.6	48	-26	0.50		5.0
Swift Current, Sask	2,392	27.37	29.99	.00	22.2	+6.2	32.8	11.6	51	-30	0.66	-0.12	6.6
Medicine Hat, Alb	2,144												
Calgary, Alb	3,428												
Banff, Alb	4,521												
Prince Albert, Sask	1,450	28.38	30.03	+.02	13.5	+10.7	23.3	3.7	44	-28	0.42	-0.32	4.0
Battleford, Sask	1,592	28.20	30.01	+.02	17.3	+11.9	26.6	8.1	47	-24	0.22	-0.10	2.0
Edmonton, Alb	2,150												
Kamloops, B. C	1,262												
Victoria, B. C	230	29.83	30.09	+.12	41.1	-0.1	44.1	38.2	49	29	2.63	-5.35	0.0
Barkerville, B. C	4,180												
Estevan Point, B. C	20												
Prince Rupert, B. C	170												
Hamilton, Ber	151	30.03	30.20	+.08	65.4	+0.7	71.8	59.1	76	52	7.56	+3.07	0.0

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Station	Altitude above mean sea level, Jan. 1, 1919	Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
Sydney, C. B. I	48	29.78	29.83	-.12	37.6	+0.5	43.3	31.8	58	22	4.88	-0.56	0.0
Halifax, N. S	88	29.79	29.90	-.11	37.6	+0.3	44.5	30.8	61	15	2.95	-2.71	2.2
Yarmouth, N. S	65	29.78	29.85	-.17	39.4	-0.5	45.1	33.8	55	19	2.54	-1.95	T.
Charlottetown, P. E. I	38	29.75	29.79	-.17	35.4	-0.1	40.1	30.7	55	14	2.45	-1.52	7.6
Chatham, N. B	28	29.76	29.79	-.18	29.0	-2.0	36.3	21.7	49	0	2.28	-1.47	3.2
Moose Jaw, Sask	1,759				31.6		44.5	18.7	59	6	0.01		0.0
Medicine Hat, Alb	2,144	27.66	29.96	-.04	35.5	+8.1	48.2	22.8	62	6	T.	-0.92	T.
Calgary, Alb	3,428	26.36	30.01	+.03	33.3	+7.5	47.2	19.5	64	6	0.22	-0.66	2.2
Banff, Alb	4,521	25.38	30.09	+.13	28.4	+2.6	36.9	19.8	50	5	0.26	-2.01	2.3
Edmonton, Alb	2,150	27.58	29.91	-.06	30.4	+7.5	42.2	81.6	53	9	0.01	-0.57	T.
Kamloops, B. C	1,262	28.79	30.12	+.16	38.2	+4.8	44.0	32.5	56	23	0.28	-1.18	0.2
Barkerville, B. C	4,180	25.60	29.97	+.07	28.8	+5.2	35.9	21.8	54	6	2.20	-1.09	21.5
Estevan Point, B. C	20				46.6		51.6	41.7	64	32	17.06		0.0
Prince Rupert, B. C	170				43.8		48.2	39.3	66	29	9.84		0.0

Chart I. Departure (°F.) of the Mean Temperature from the Normal, December, 1928

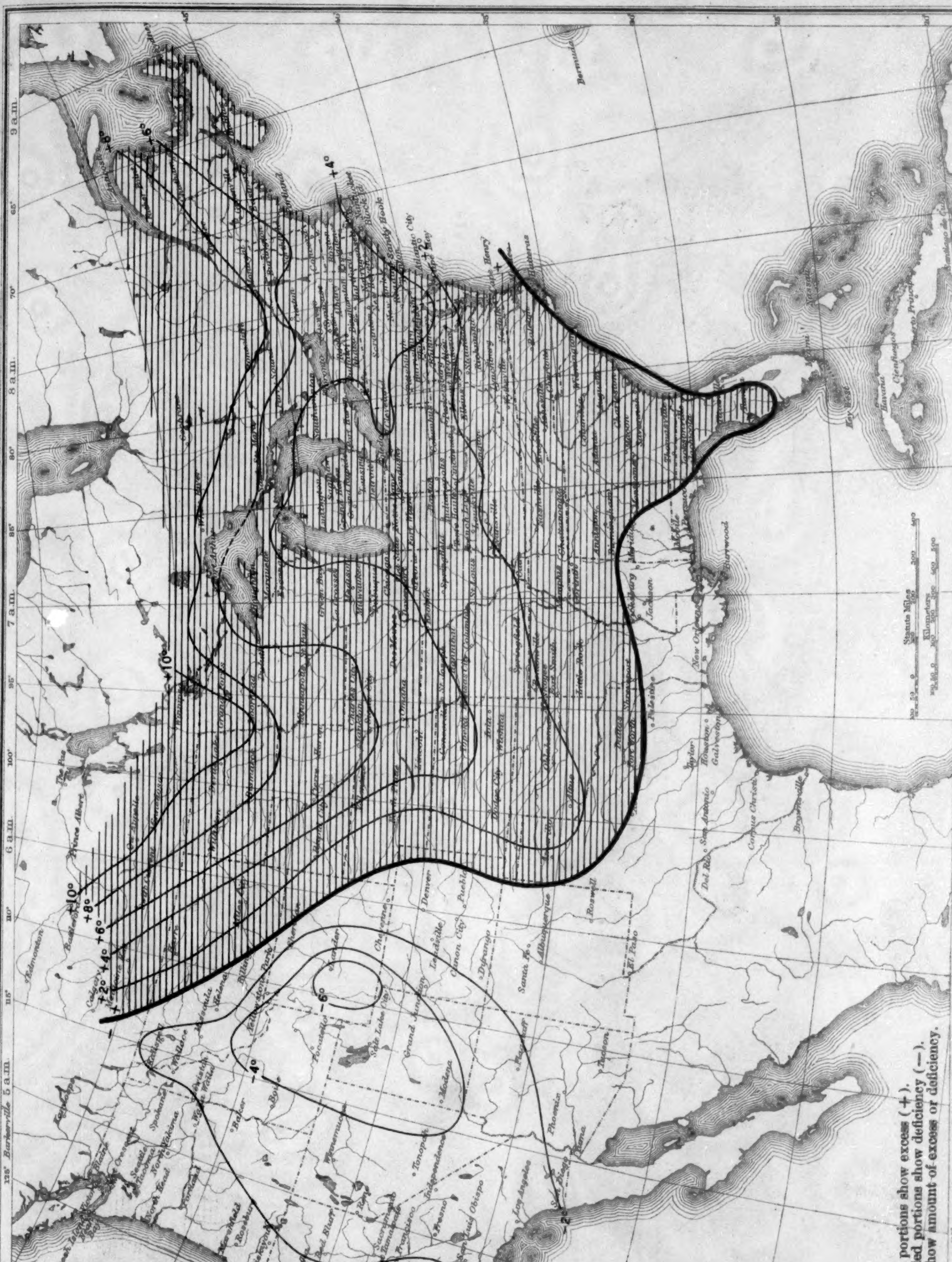
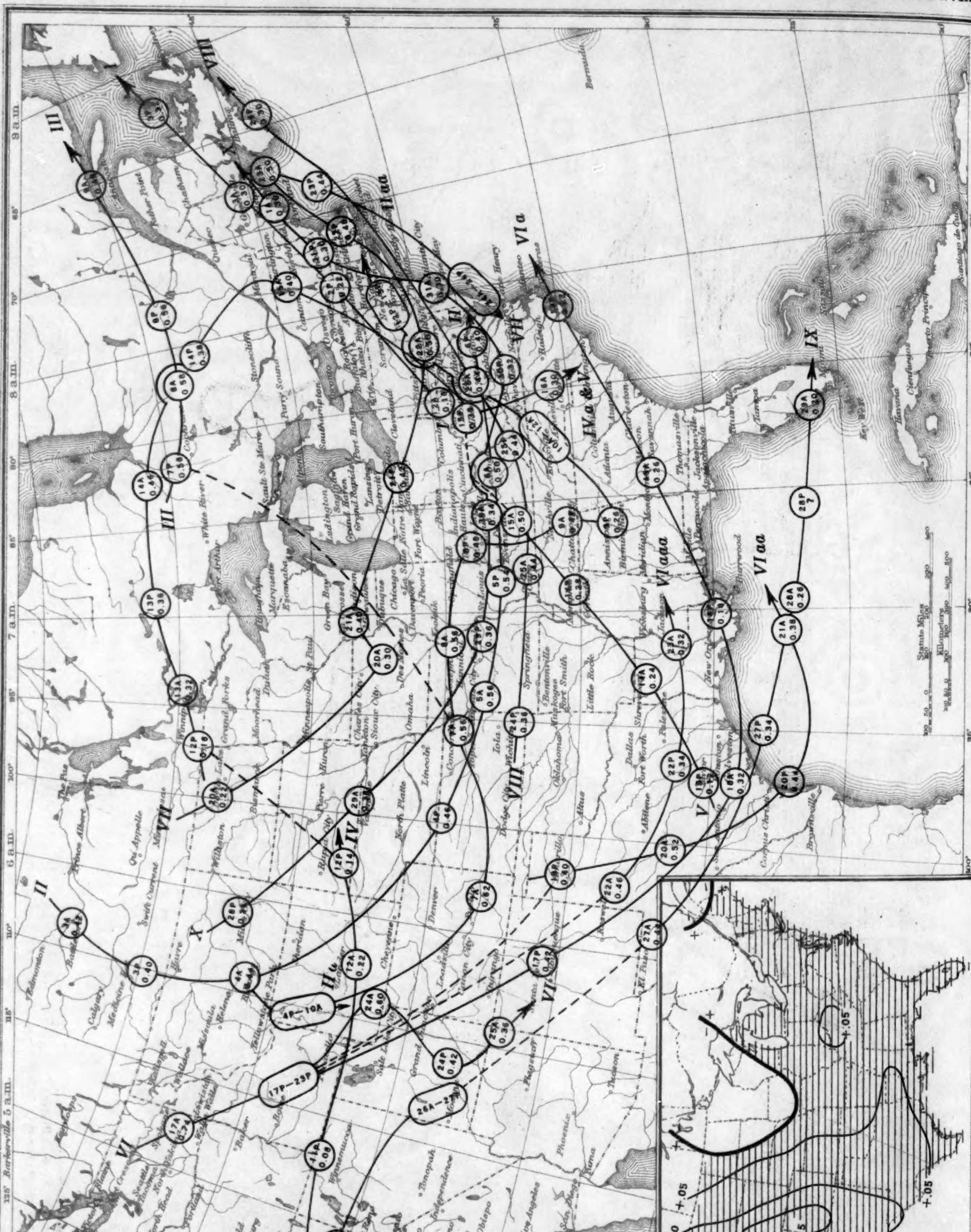


Chart II. Tracks of Centers of Anticyclones, December, 1928. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by Wilfred P. Day)



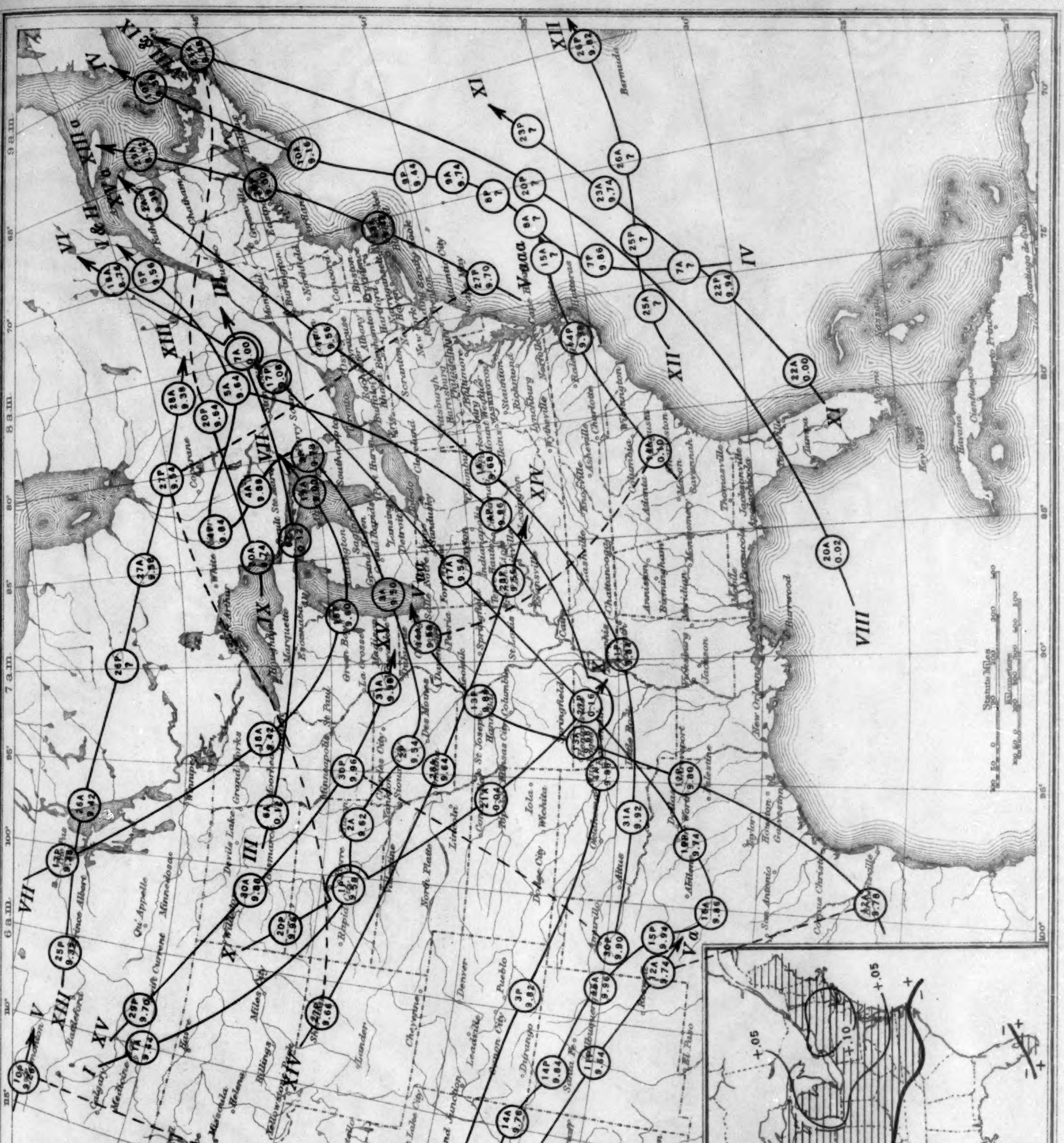
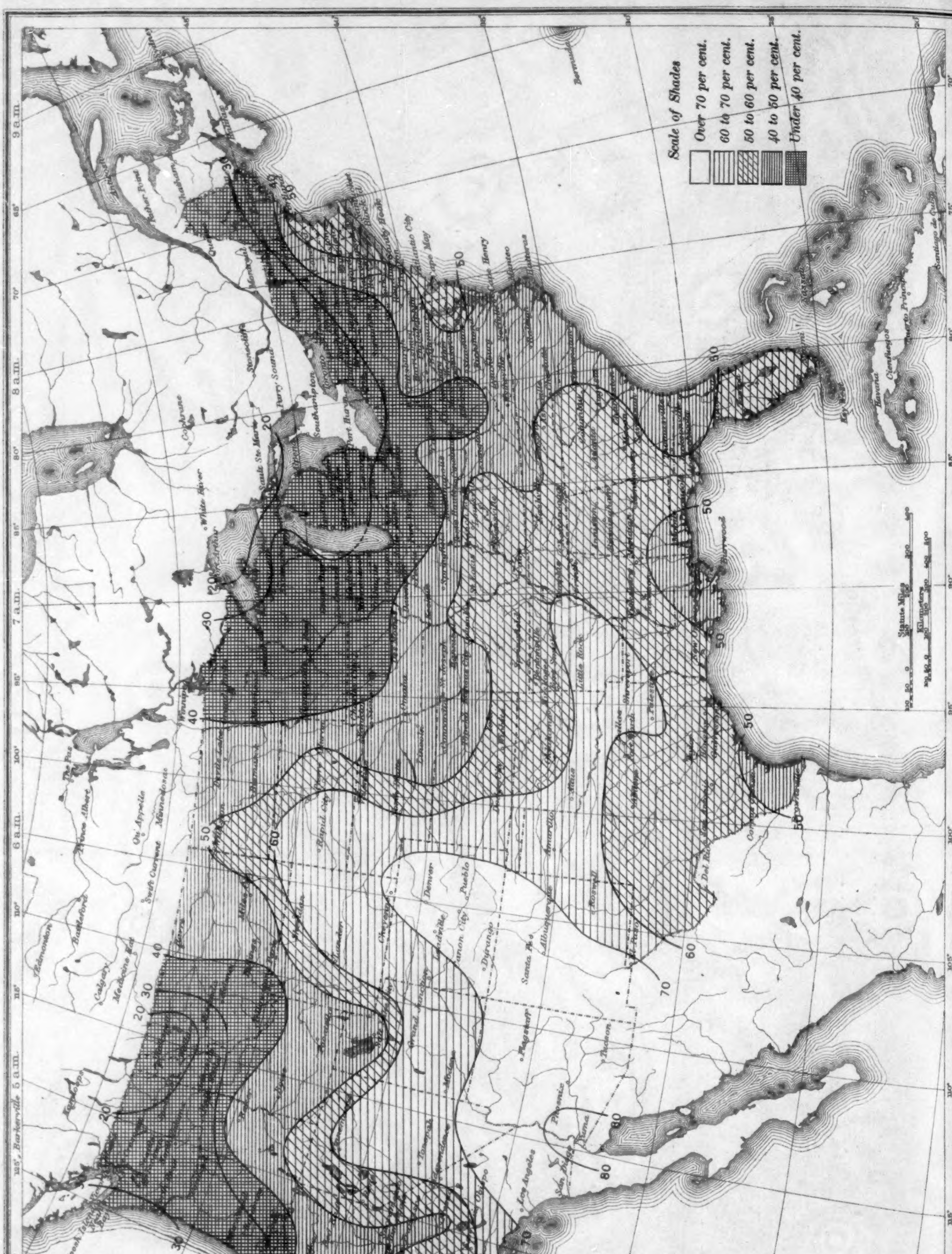


Chart III. Tracks of Centers of Cyclones, December, 1928. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by Wilfred P. Day)

Chart IV. Percentage of Clear Sky between Sunrise and Sunset, December, 1928



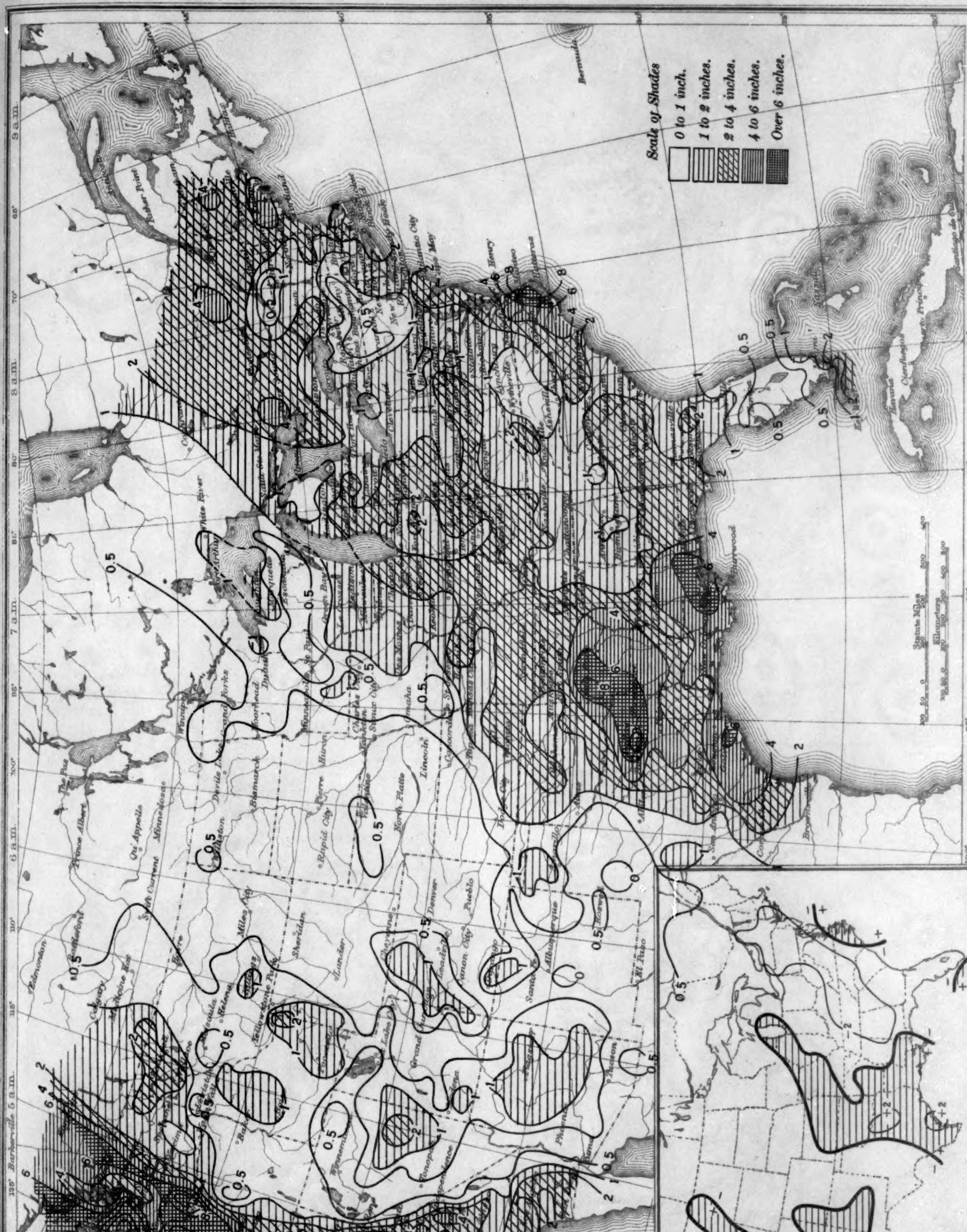


Chart V. Total Precipitation, Inches, December, 1928. (Inset) Departure of Precipitation from Normal

Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, December, 1928

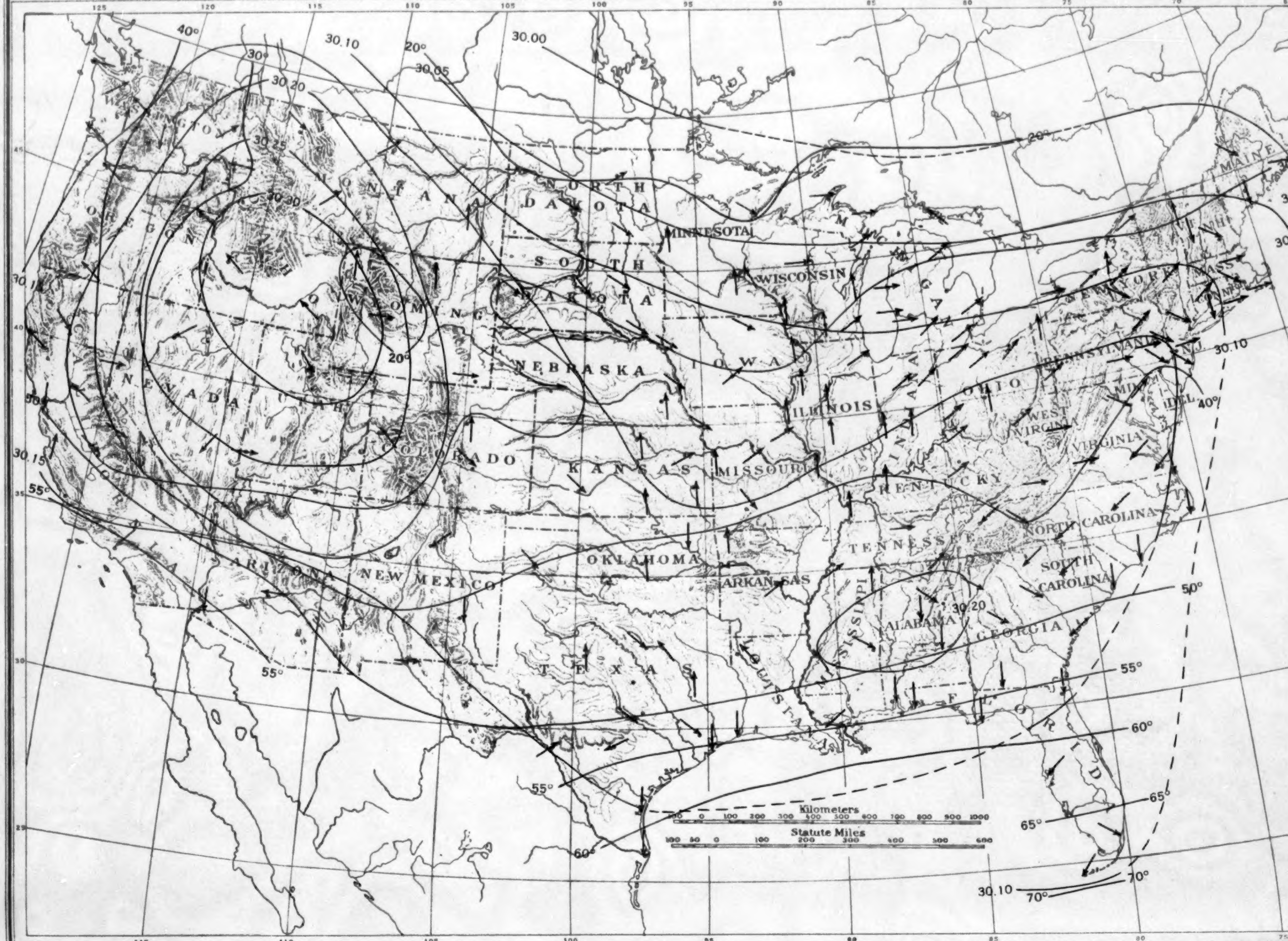


Chart VII. Total Snowfall, Inches, December, 1928. (Inset) Depth of Snow on Ground at end of Month

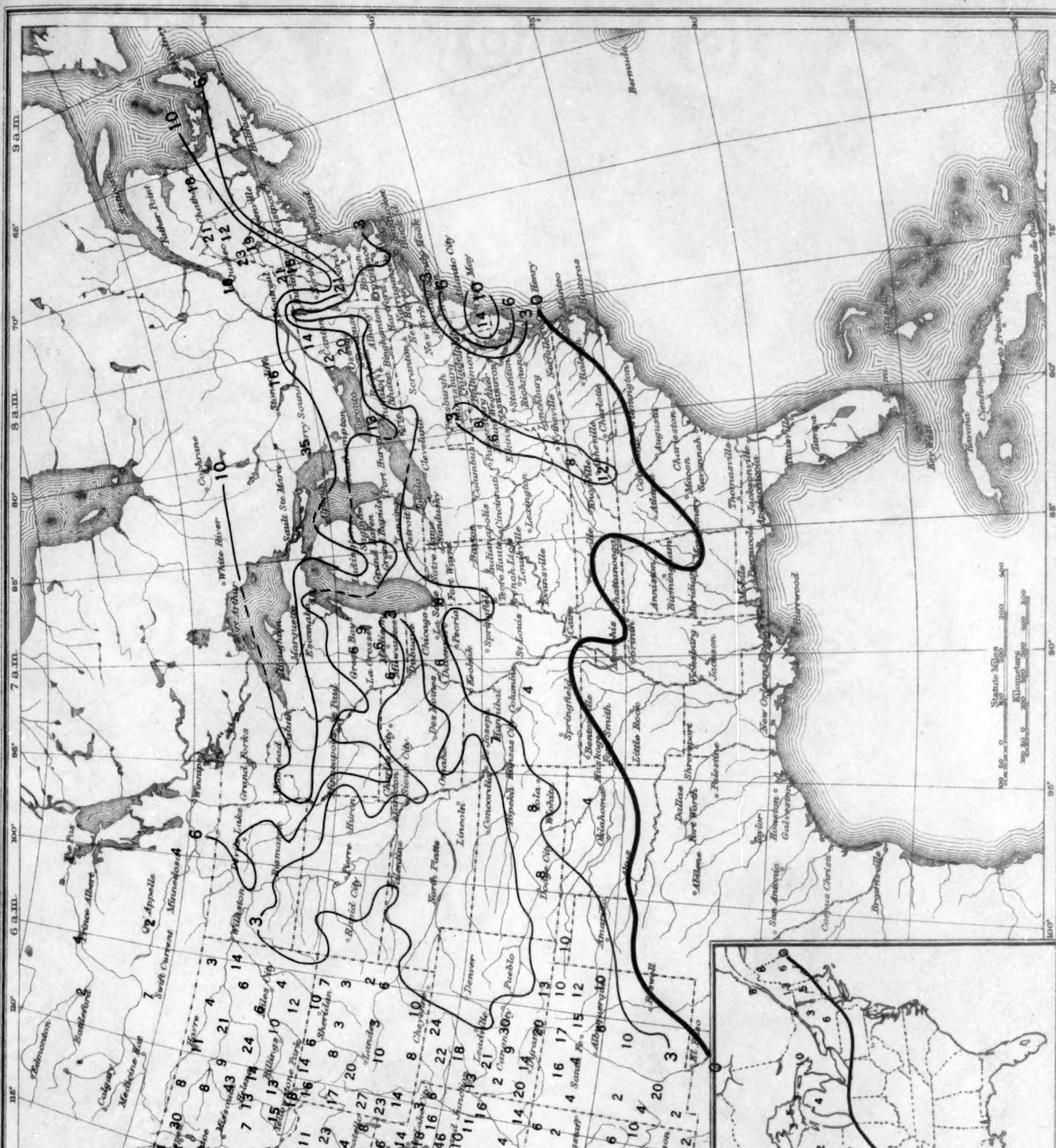


Chart VII. Total Snowfall, Inches, December, 1928. (Inset) Depth of Snow on Ground at end of Month

Chart VIII. Weather Map of North Atlantic Ocean, December 8, 1928
(Plotted by F. A. Young)

Chart VIII. Weather Map of North Atlantic Ocean, December 8, 1928
(Plotted by F. A. Young)

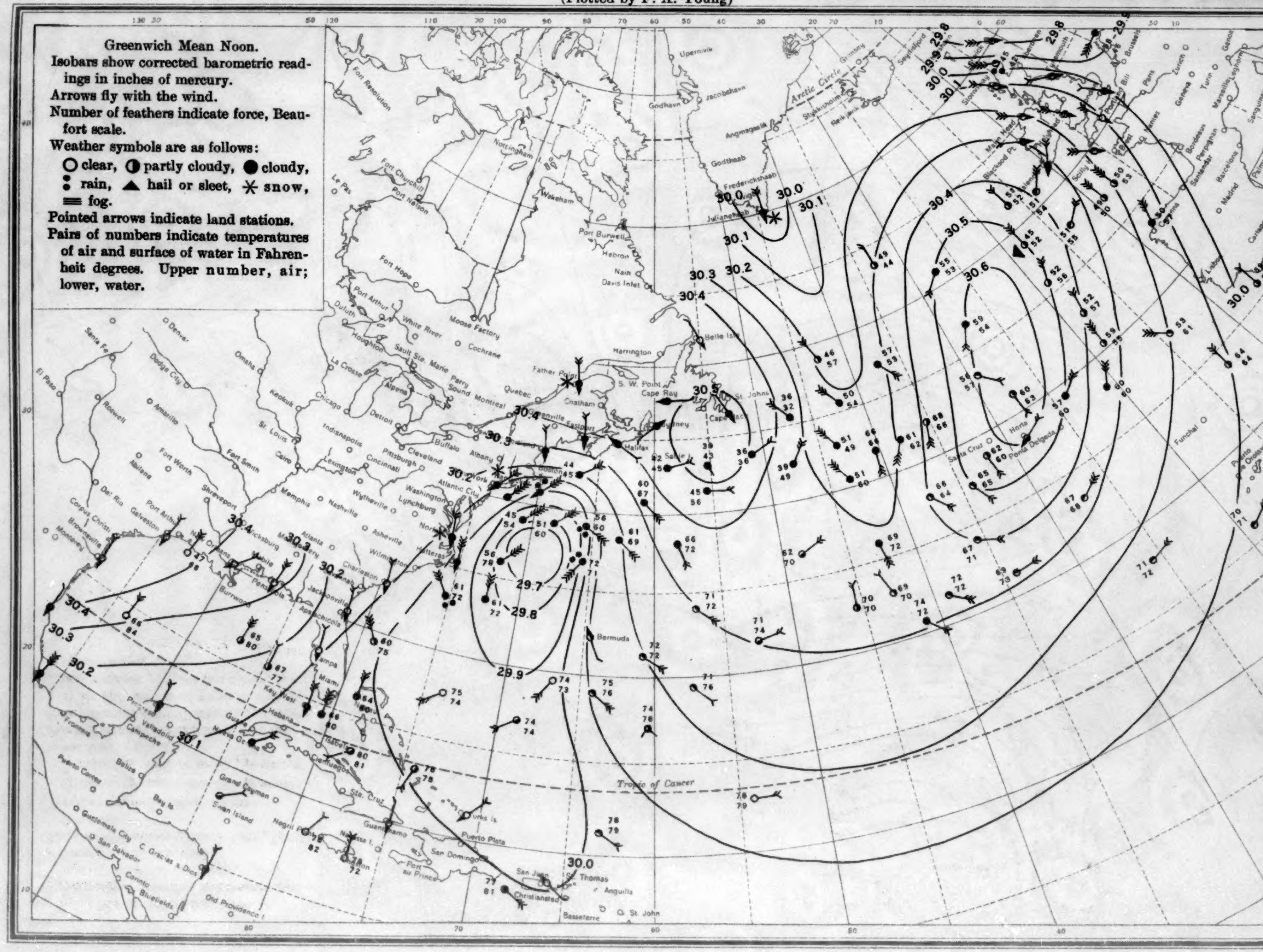


Chart IX. Weather Map of North Atlantic Ocean, December 9, 1928

(Plotted by F. A. Young)

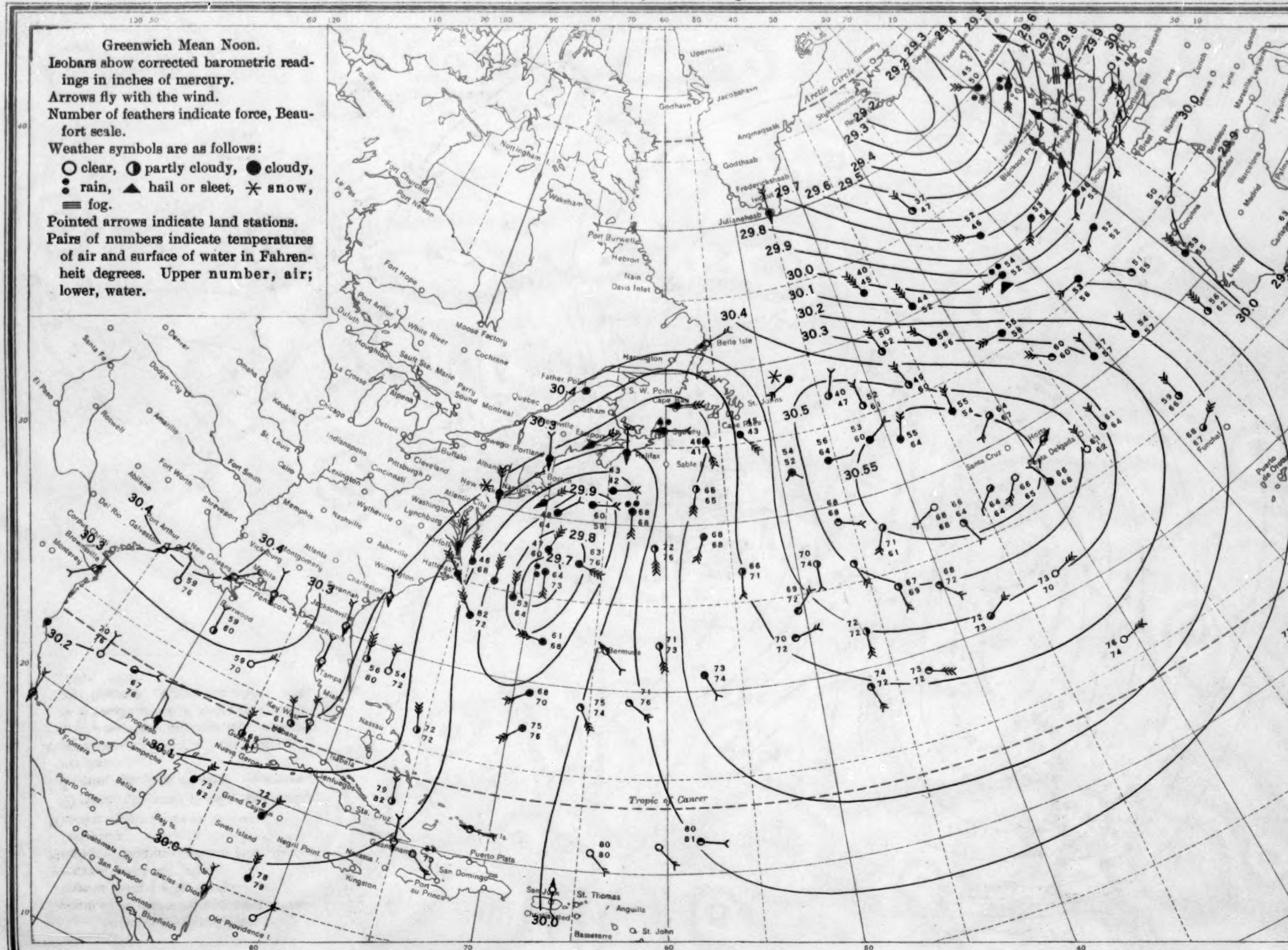


Chart X. Weather Map of North Atlantic Ocean, December 10, 1928

(Plotted by F. A. Young)

Chart X. Weather Map of North Atlantic Ocean, December 10, 1928
(Plotted by F. A. Young)

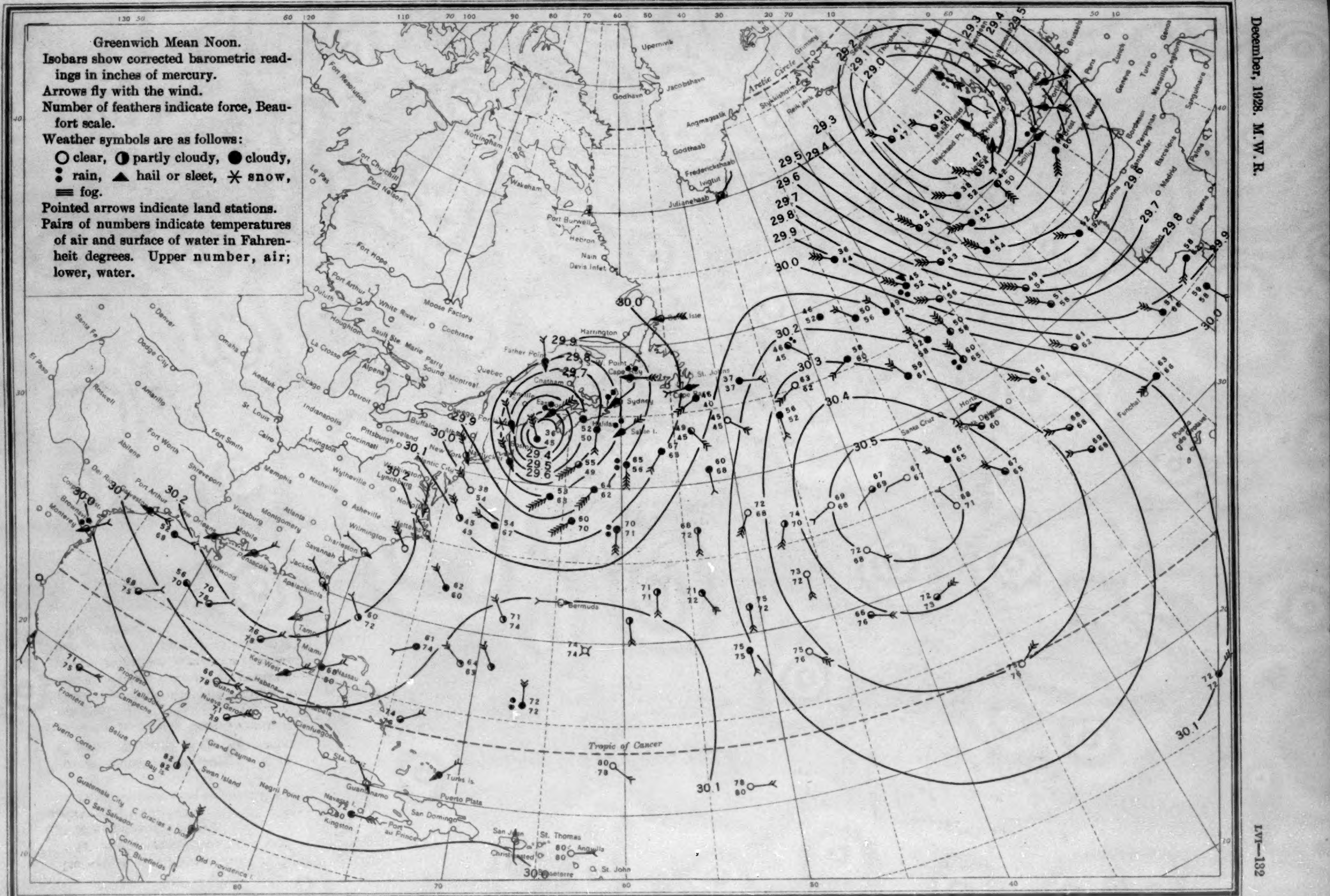
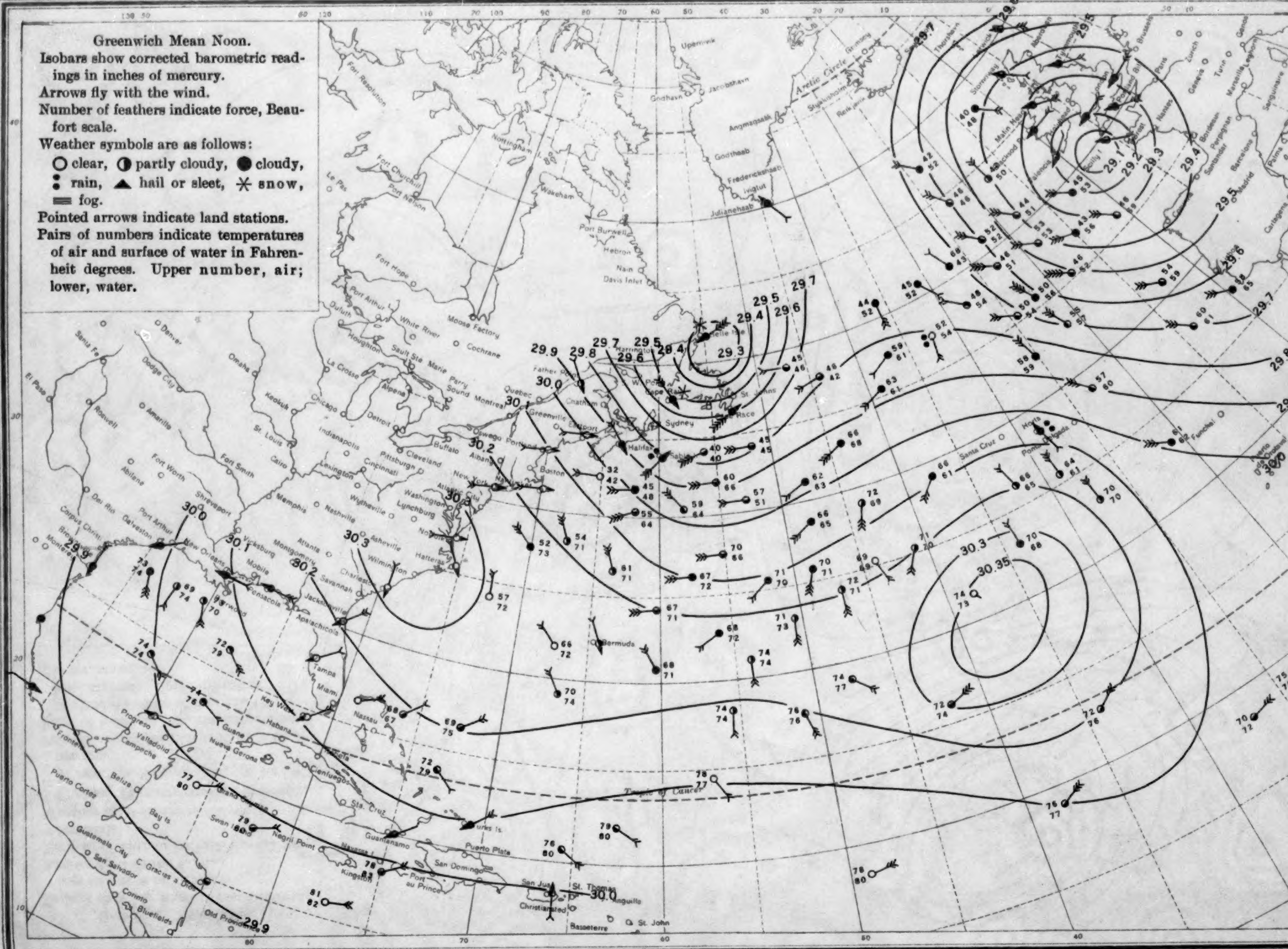


Chart XI. Weather Map of North Atlantic Ocean, December 11, 1928

(Plotted by F. A. Young)



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